Department of AGRICULTURE FISHERIES & FORESTRY - AUSTRALIA
Land & Water Resources Research & Development Corporation
CVAP Climate Variability in Agriculture R&D Program
Australian Grassland and Rangeland Assessment by Spatial Simulation

The Aussie GRASS
Southern Pastures Sub-project

FINAL REPORT

April 2001

Queensland Government Natural Resources and Mines
Agriculture Western Australia
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NSW Agriculture
PRIMARY INDUSTRIES AND RESOURCES SA
South Australia
LAND & WATER CONSERVATION
Queensland Government Department of Primary Industries

Australian Grassland and Rangeland Assessment by Spatial Simulation

(*Aussie GRASS*)

Southern Pastures Sub-project

QNR9

Final Report

for the

Climate Variability in Agriculture Program

April 2001

Rob Richards, Ian Watson, Judy Bean, John Maconochie, Steve Clipperton, Greg Beeston, Daryl Green and Ron Hacker

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Table of contents

1 Sub-project details

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2 Introduction

The Final Report of the 'Development of a National Drought Alert Strategic Information System' project (Brook 1996) made a number of research and extension recommendations should a second round of funding be obtained to continue the work. These recommendations then formed the basis for the Aussie GRASS proposal to the Climate Variability in Agriculture Program (CVAP) within the Land and Water Resources Research and Development Corporation (LWRRDC).

A key component of the Aussie GRASS proposal was the recognition that use of the GRASP (Littleboy and McKeon 1997) pasture production model in the prototype national modelling framework may not be optimal, particularly for those vegetation types that differed significantly from the tropical C4 grasslands where GRASP was originally developed. These concerns were based on a number of climatic and biological aspects that differentiate southern Australian vegetation communities from those in the north, including rainfall seasonality, plant growth and decay rates, plant community demographics and functionality, dynamic shrub processes, shrub/tree browse component, and plant community composition. Hence the Southern Pastures sub-project was charged with refining the national spatial model so as to ensure its applicability to the southern pastures of Australia.

The specific objectives for the Southern Pastures sub-project will now be listed and work undertaken to achieve these objectives will be detailed.

3 Southern Pastures sub-project objectives

The objectives of the Southern Pastures sub-project were:

1) Undertake a rigorous systems review of IMAGES, ARIDGROW, SEESAW, and GRASP for use in southern Australia.

2) Develop a consensus view of what model, models, or model combination should be used.

3) Collate the pasture and shrubland data necessary to parameterise the models.

4) Validate the model against historic time series data sets, annual ground monitoring and vehicle transects.

5) Interface the best model or models to the 'Aussie GRASS' spatial framework.

6) Based on the best southern Australian models, develop regional specific information products aimed at the pastoral industry, catchment management committees and State government agencies in: decision support, vegetation management, grazing management, drought declaration, and land degradation prevention.

4 Achievements

This section will briefly outline how each of the inter-related objectives has been achieved. Where more detailed data is available, and considered of value to the reader, these will be presented as separate sections within this report.

4.1 Objective 1: Undertake a rigorous systems review of IMAGES, ARIDGROW, SEESAW, and GRASP for use in southern Australia

In order to undertake a review of the relevant pasture production models a systematic approach was taken for each model, namely:

1) obtain model documentation and available literature;
2) examine and compare model biological processes and integrity;
3) obtain model source code (except SEESAW);
4) identify and collate suitable data sets to use with the model (see Section 4.3); and
5) assess model performance.

While the reviews of IMAGES (Hacker *et al*. 1991) and ARIDGROW (Hobbs *et al*. 1994) were undertaken by the Aussie GRASS project team, a contract was established between CSIRO and the Department of Land and Water Conservation in order to achieve the above processes for the SEESAW pasture production model. A document detailing the operation and function of the SEESAW model was produced by CSIRO (Hodgkinson and Marsden 1998) and used in the review of the model. Similar documentation was obtained for IMAGES and ARIDGROW.

Details on the review of the ARIDGROW, IMAGES and SEESAW pasture production models can be found in sections 5.1, 5.2 and 5.3 respectively.

4.2 Objective 2: Develop a consensus view of what model, models, or model combination should be used

The models were assessed on the basis of their performance (i.e. ability to account for variability in observed data), input data requirements, ease of calibration, and potential for incorporation within the existing spatial modelling framework.

A comparison of the CSIRO ephemeral pasture production model ARIDGROW and GRASP found that calibration of GRASP allowed it to account for a higher amount of variation in total standing dry matter (TSDM) for four of the fives sites for which data were available in central Australia. A full report on the simulations and comparison of the ARIDGROW and GRASP models is presented in Section 5.1.

Watson (1999) in his detailed examination of the simulation results of IMAGES for the Boolathana grazing trial identified three factors that would prevent the inclusion of shrub biomass estimates in the Aussie GRASS spatial framework: 1) no model is currently available that can simulate browse biomass well; 2) for most vegetation types the separation of browse into ‘eaten’ and ‘uneaten’ will be very difficult; and 2) shrub biomass will always depend on the condition of the system. Thus Watson (1999) recommended that: 1) it was naïve for the Aussie GRASS project to assume that it could model absolute biomass of shrub-dominated systems, especially given vegetation mapping resolution would not allow edible shrub density to be mapped with any accuracy; and 2) that resources were best concentrated on parameterising the existing Aussie GRASS model as a best estimate of herbage biomass production in shrub dominated systems. The GRASP model has previously been shown by McKeon *et al.* (1996) to simulate 62 – 72% of the variation in observed non-shrub biomass for the four Boolathana sites examined in their work. The full findings of the work by Watson (1999) and additional work using data from Roshier, NSW, are contained in Section 5.2.

Details of the evaluation of the SEESAW and GRASP models are contained in Section 5.3. Existing GRASP parameter sets were tested but independent validation was only achieved on a few sites in western NSW for which data were available. GRASP was then calibrated to the first two TSDM observations in each time series using the single parameter 'potential regrowth rate'. Other site parameters (available soil water, tree density, species composition) were estimated from inputs used in SEESAW. The use of calibrated site-specific regrowth parameters or an average across the eight sites explained a reasonable proportion of variation ($r^2 > 0.69$) for six sites. Comparison with SEESAW simulations, without further calibration, indicated that GRASP and SEESAW were in reasonable agreement ($r^2 > 0.70$) for seven sites and very close agreement ($r^2 > 0.88$) for four sites. Whilst GRASP does not attempt to represent the variation in behaviour of plant guilds over time that SEESAW does, nevertheless, for sites of known composition, GRASP can represent a similar proportion of variation in TSDM as SEESAW. Results from the SEESAW simulations (detailed in Marsden and Hodgkinson 1998) also show that whilst total biomass may have been simulated well, there was often poor agreement between each of the observed and simulated guilds, i.e. errors in simulation of annual forbs, perennial forbs, C_3 grasses and C_4 grasses cancelled each other out so as to produce a good simulation of TSDM.

Given the above finding it was recommended that there is currently little potential benefit to be gained from the inclusion of the ARIDGROW, IMAGES or SEESAW models within the Aussie GRASS modelling framework, and that the GRASP model was the preferred option in terms of both simulation performance and input data requirements.

4.3 Objective 3: Collate the pasture and shrubland data necessary to parameterise the models

A thorough literature search of suitable data sets was undertaken in order to achieve this objective. Of the fifteen data sets collected by NSW Agriculture and the Department of Land and Water Conservation (DLWC), only five (Bean and Clipperton 1999) were suitable for model parameterisation and validation as per *Objective 4*. CSIRO supplied an additional six data sets (Marsden 1998) that were used for parameterisation.

Unfortunately, difficulties were experienced in establishing historic data sets of suitable quality for calibration and validation of the models, and hence comparison of model outputs. The suitability of data was limited by incompleteness, suspect data, inappropriate data types, and differences in temporal and spatial applicability. The numerous difficulties encountered in the use of these historic data sets emphasises the need for future data from grazing trials etc. to be collected with a view to their being used in a modelling framework. The GUNSYNpD/SWIFTSYND technique (Day and Philp 1997) provides one approach whereby quality data suitable for pasture modelling can be collected quickly and efficiently.

In addition to the above data used in the review of the models, spatial data were also collected to use as inputs to the national model. This included improved data on kangaroo and goat numbers, soil layer characteristics and vegetation community composition. In conjunction with the Bureau of Meteorology (BoM), the NSW project team arranged for eighteen producers to join the Bureau's volunteer NSW rainfall reporting network. An unsuccessful attempt was also made to establish a system to obtain timely stock figures on an annual basis from the Rural Lands Protection Boards in western NSW.

4.4 Objective 4: Validate the model against historic time series data sets, annual ground monitoring and vehicle transects

As a result of the model evaluations undertaken as part of *Objective 2*, the decision was made to continue to use GRASP across the southern pastures within the Aussie GRASS modelling framework. The next step was to spatially calibrate and validate the Aussie GRASS model. Three sources of data were used for this purpose: 1) 'spider mapping' data; 2) Rangeland Assessment Program (RAP) data; and 3) NOAA Pathfinder NDVI imagery. (N.B. All historical time series data collated as part of *Objective 3* were used in the model evaluation process)

The majority of the spatial model calibration and validation was performed using data sets collected from extensive field surveys, or spider mapping, in each of the relevant States. A summary of these field surveys can be found in Section 6.5. Field surveys took place between mid 1998 and early 2000. Validation parameters collected included visual estimates of pasture biomass (almost 60,000), tree/shrub cover and chenopod density. Data were collected using a computerised data acquisition system consisting of a laptop computer, global positioning system and on screen real time map navigation using satellite imagery. While each State's methods varied slightly, they were based on the technique developed by Hassett *et al*. (2001) as part of the initial Development of a National Drought Alert Strategic Information System project.

Some difficulties were experienced in collecting data in some vegetation communities such as the heavily infested 'woody shrub' communities of western NSW. Attempts were made to establish a relationship between tree/shrub basal area and foliage projected cover. However, no reliable relationship was found although a very strong relationship existed between foliage projected cover and canopy cover. Data collected during extensive field surveys are the most critical for model calibration/validation but such surveys are very resource demanding. There is scope for further refinement of methods used and further validation using spider mapping techniques.

The RAP data set has been collected by DLWC since October 1989 and includes measures of pasture biomass. Data were available for 334 locations (Figure 1) with each site having between 2-11 observations. More information on the spatial model calibration/validation is presented in Section 7.

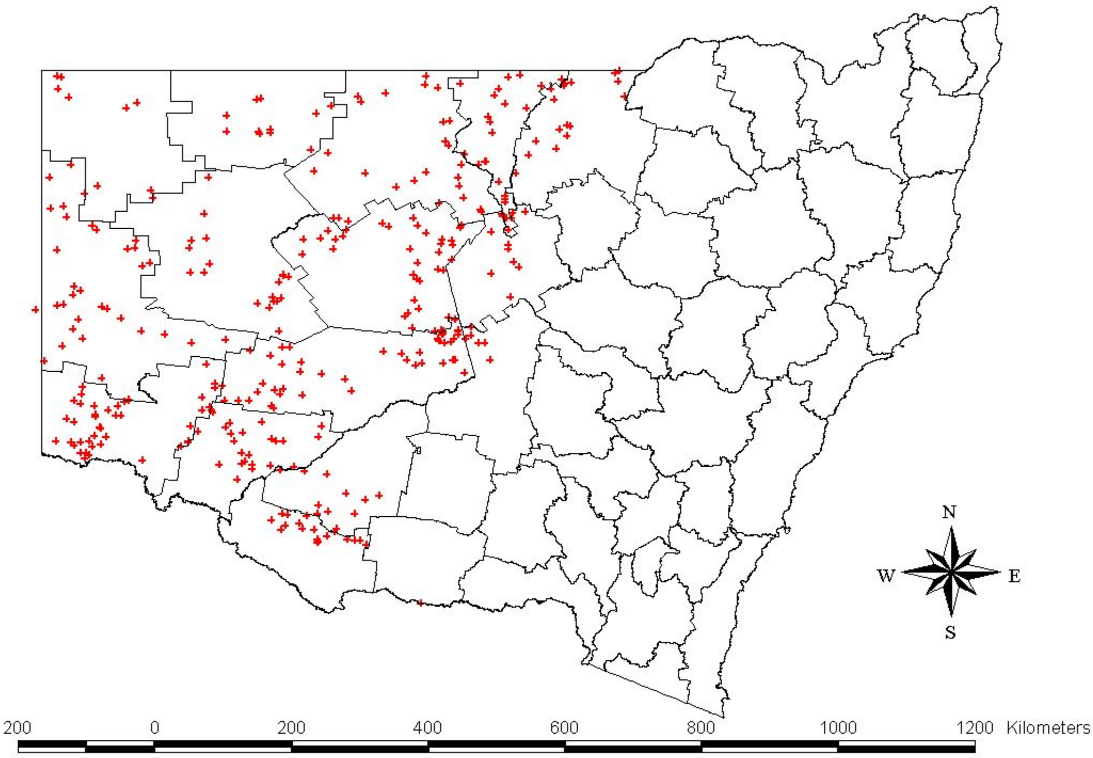

Figure 1. Locations of RAP biomass sites used in calibration/validation of the Aussie GRASS model. Internal boundaries are Rural Lands Protection Board (RLPB) districts.

4.5 Objective 5: Interface the best model or models to the 'Aussie GRASS' spatial framework.

Given the conclusions of work undertaken as part of *Objective 2*, it was not necessary to interface any of the reviewed models into the national Aussie GRASS modelling framework within the scope of this project.

4.6 Objective 6: Based on the best southern Australian models, develop regional specific information products aimed at the pastoral industry, catchment management committees and State government agencies in:- decision support, vegetation management, grazing management, drought declaration, and land degradation prevention.

Information products derived and used included a range of absolute and relative data and spatial maps. These included monthly growth and growth relative to historic records for 3, 6, 12 and 24-month periods, and rainfall relative to historic records for the same periods. Other information products included spatial maps of grassfire risk and seasonal outlooks for rainfall and pasture growth. These products were promoted through the Extension sub-project (see Paull *et al*. 2001 for more details). Many of these information products were well accepted and generated considerable interest from a range of government and non-government users such as Rural Fire Services, Rural Land Protection Boards, conservation agencies, Landcare groups and individual landholders.

5 Model evaluations

One of the main tasks of the Southern Pastures sub-project of Aussie GRASS was to examine the suitability of pasture growth models developed for this area for inclusion in the Aussie GRASS spatial model. These 'local' models, along with GRASP, were to be examined in 'desk top' studies to compare how they simulated the important processes of the pasture system. The models were also to be assessed on the basis of their input data requirements, ease of calibration, and potential for incorporation within the existing spatial modelling framework. Three models have been developed for parts of the southern pastures region: the shrublands model IMAGES; the central Australian ARIDGROW model; and the western NSW SEESAW model.

5.1 Central Australia

In the following sections an overview of the ARIDGROW model will be provided and simulation output documented for five locations in central Australia (Section 5.1.1). Similarly, issues regarding the running of the GRASP model at these same sites will be discussed and the output compared with that of ARIDGROW (Section 5.1.2).

5.1.1 ARIDGROW

5.1.1.1 Introduction

ARIDGROW (Hobbs *et al.* 1994) was designed as a simple, robust water balance and plant growth model for use in the rangelands of central Australia. The model parameters were based on data for five landscape types collected over two years (Table 1). Rainfall data were collected at each site while other climate data used in the model development were from the Bureau of Meteorology's Alice Springs' recording station.

5.1.1.2 Inputs

The only inputs required by ARIDGROW are rainfall and pan evaporation (potential).

5.1.1.3 Processes modelled

ARIDGROW simulates soil water balance, pasture growth and decay on a daily basis. Pasture growth occurs when available soil water (ASW) is greater than or equal to wilting point (WP). Plant decay occurs in those periods where ASW is less than WP.

5.1.1.3.1 Soil water

Soil water balance is simulated for a single layer profile of 500 mm using a simple 'bucket' model, i.e. run-off and deep drainage occur only after the soil profile is fully saturated. Plant biomass/vegetation cover effects on evapotranspiration (ET) are ignored on the assumption that 'in sparsely vegetated arid landscapes, the effects of vegetation and meteorological factors on soil moisture loss are less clear than the dominating effect of soil surface evaporation' (Hobbs *et al.* 1994).

Table 1. Data on the five sites used in the calibration of the ARIDGROW model. All sites were within 160 km of Alice Springs (from Hobbs 1994, Hobbs *et al*. 1994).

Location	Landscape	Landform /soil texture	Trees and shrubs	Herbage
Site 1 25^0 00' S 133^0 12' E	Bluebush shrubland	Gentle erosional slopes /silty clay loam	*Maireana astrotricha* (L. Johnson) P.G. Wilson (6% cover)	*Maireana carnosa* (Moq.) P.G. Wilson *Enneapogon cylindricus* N. Burb. *Helichrysum ayersii* F. Muell. *Helipterum charsleyae* F. Muell. Enneapogon avenaceus (Lindley) C.E. Hubb.
Site 2 23^0 59' S 133^0 49' E	Calcareous shrubby grassland	Undulating limestone hills and rises /loam	*Acacia kempeana* F. Muell. (1% cover)	*Enneapogon cylindricus* N. Burb. *Enneapogon avenaceus* (Lindley) C.E. Hubb. *Helipterum floribundum* DC. *Sida* spp. *Tripogon lolliformis* (F. Muell.) C.E. Hubb.
Site 3 23^0 43' S 133^0 36' E	Open floodplain	Flat drainage floors and floodouts /sandy clay loam	*Maireana aphylla* (R. Br.) P.G. Wilson *Sclerolaena bicornis* Lindley (2% cover)	*Sclerolaena costata* (R. anders.) A.J. Scott *Tripogon lolliformis* (F. Muell.) C.E. Hubb. *Indigofera linnaei* Ali *Maireana scleroptera* (J. Black) P.G. Wilson *Sida* spp.
Site 4 23^0 50' S 134^0 45' E	Gidyea open woodland	Slightly dissected alluvial plains /silty clay loam	*Acacia georginae* Bailey (4% cover)	*Tribulus terrestris* L. *Stenopetalum nutans* F. Muell. *Salsola kali* L. *Enteropogon acicularis*(Lindley) Lazarides *Fimbristylis dichotoma* (L.) M. Uahl
Site 3 23^0 34' S 133^0 34' E	Mixed open woodland	Flat plains /sandy loam	*Atalaya hemiglauca* (F. Muell. *Acacia aneura* Benth. *Ventilago viminalis* Hook. (6% cover)	*Tripogon lolliformis* (F. Muell.) C.E. Hubb. *Sclerolaena costata* (R. anders.) A.J. Scott *Enteropogon acicularis*(Lindley) Lazarides *Salsola kali* L. *Digitaria coenicola* (F. Muell.) Hughes

Soil water loss or ET is calculated with a negative exponential function using ASW, rain and potential evaporation (PE). ASW and rain are used in the following equation to calculate a relative moisture index (MI):

$$MI = (ASW - SW_{min}) / (FC - SW_{min})$$

where SW_{min} is minimum soil moisture on air drying (mm); and
FC is field capacity (mm).

The MI is then multiplied by the PE to calculate daily ET. Or, in other words, each day's MI may be calculated as (Figure 2):

$MI_t = MI_{t-1} * exp^{-k.PE}$

where k is an evaporative constant.

Rainfall may add additional moisture to the profile up to the field capacity. Thus the above equation is rewritten as:

$MI_t = \min(1.0, MI_{t-1} + Rn_t) * exp^{-k.PE}$

and Rn_t is calculated as:

$Rn_t = rain / (FC - SW_{min})$

All measurement units are in mm. See Table 2 for the calibrated values of k for each site.

5.1.1.3.2 Plant growth

The effects of light and temperature on plant growth are assumed to be non-limiting and thus ignored. The effect of existing herbage on plant growth is also ignored on the assumption that growth is driven by actual ET. Thus plant growth is solely driven by soil moisture availability. Given ASW is greater than or equal to WP, plant growth is calculated as (Figure 3):

growth = g * ET + s

where g and s are constants.

Unlike the soil water balance where each site had it's own model, a generalised plant growth model using data from four of the sites was developed (see Table 2 for parameter values). Site 3 (open floodplain) was excluded from this analysis as inclusion of its data produced a more complex model. All measurement units are in $g/m^2/d$.

5.1.1.3.3 Plant decay

Plant decay occurs when ASW is below WP and is represented by a logistic curve as a function of peak TSDM after a growth inducing rainfall event, time since the peak, and half-life of the biomass. No direct effect of stock on decay is simulated. It is assumed that stocking rates in the region are light and steady and that the parameters in the decay function account for this grazing pressure. Plant decay is calculated as (Figure 4):

$TSDM_t = TSDM_{peak} * (a + exp^{-b.h}) / (a + exp^{-b.(h-tp)})$

where a and b are constants;
h is the half-life of the biomass; and
tp is the time since the peak TSDM (days).

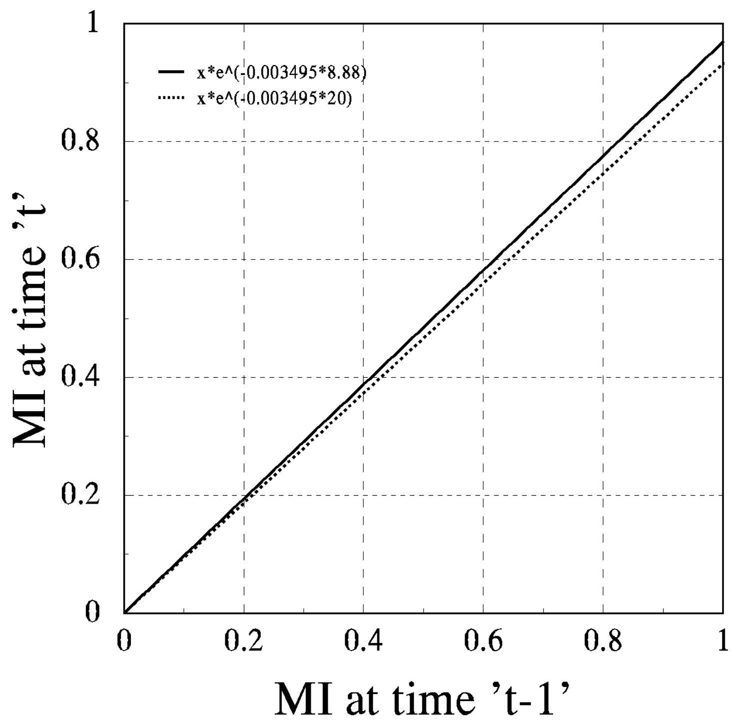

Figure 2. Change in Moisture Index (MI) on a daily time step as a function of potential evaporation (PE) assuming no rainfall. Plotted are the relationships when PE = 8.88 mm/d (Alice Springs mean for 1989-91) and PE = 20 mm/d (Alice Springs maximum for 1989-91).

Table 2. ARIDGROW site-specific parameters for the five sites of Hobbs *et al*. (1994).

Parameter	Site specific parameter values					
	Bluebush shrubland	**Calcareous shrubby grassland**	**Open floodplain**	**Gidyea open woodland**	**Mixed open woodland**	**Mean for central Australia**
Evaporative constant – k	0.003495	0.006109	0.007281	0.008927	0.008048	0.006772
Maximum soil moisture (mm/0-500 mm)	134.9	94.7	139.0	107.6	117.2	118.7
Minimum soil moisture (mm/0-500 mm)	49.7	31.0	52.5	26.0	31.5	38.1
Initial soil moisture (mm/0-500 mm)	49.7	31.0	52.5	26.0	31.5	38.1
Wilting point (mm/0-500 mm)	69.8	38.7	59.8	33.4	0.7	53.1
Plant growth rate constant – g ($g/m^2/mm$)	0.334					
Plant intercept constant - s (g/m^2)	0.148					
Plant decay constant – a	0.66	0.66	0.66	0.66	0.66	0.66
Plant decay constant – b	0.013	0.013	0.013	0.013	0.013	0.013
Half-life of biomass (days)	133	133	133	133	133	133

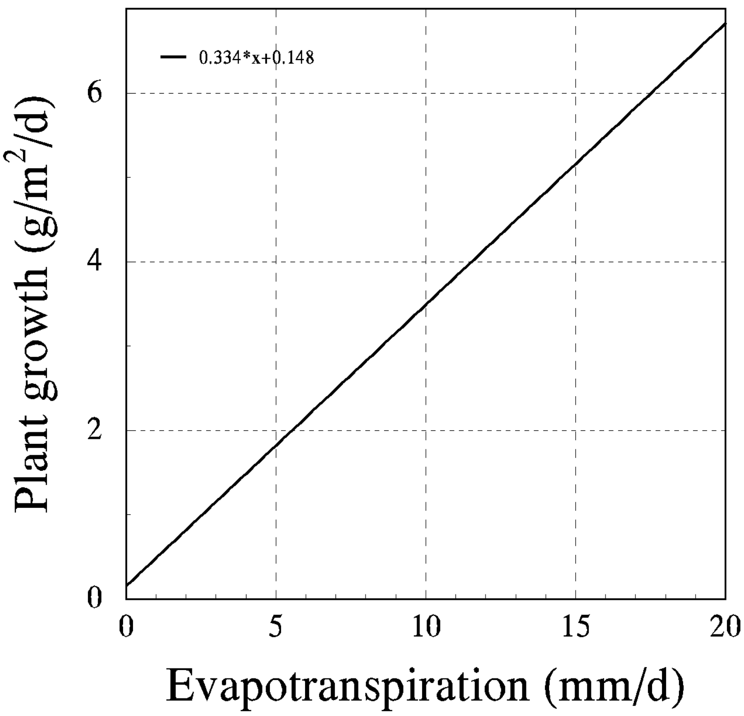

Figure 3. Relationship between plant growth (g/m^2) and ET (mm/d) assuming ASW greater than or equal to WP.

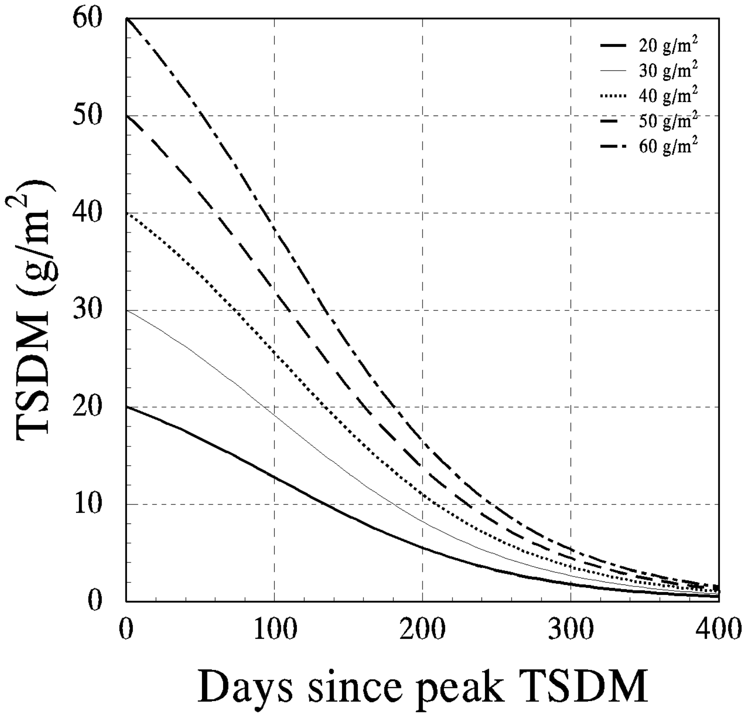

Figure 4. Decline in peak TSDM over time assuming ASW less than WP.

As for the plant growth model, a generalised plant decay model was calibrated using data from all the sites (see Table 2 for parameter values). TSDM is measured in terms of g/m^2.

5.1.1.4 Simulations with ARIDGROW (Dbase IV version)

The Dbase version of ARIDGROW (dated February 1 1995) was supplied by Trevor Hobbs along with the daily rainfall data for each of the five sites (Figure 5). Pan evaporation from Alice Springs was used in the model runs (Figure 6). The site-specific parameters are presented in Table 2.

5.1.1.4.1 Soil water

The Dbase version of ARIDGROW was run for each of the sites using the site-specific rainfall and Alice Springs' evaporative data. The results for the open floodplain and mixed open woodland sites are shown in Figure 7. The correlations between observed and predicted soil water for all five sties are listed in Table 3. For the open floodplain site, Hobbs *et al*. (1994) reported a correlation (r^2) of 0.97 whilst the correlation found here was 0.878 ($P<0.001$, using 23 rain days and 27 soil water observations). For the mixed open woodland site, Hobbs *et al*. (1994) reported a correlation (r^2) of 0.86 whilst the correlation found here was either 0.778 ($P<0.001$, using 24 rain days and 27 soil water observations) or 0.709 ($P<0.001$, using 42 rain days and 36 soil water observations). The first correlation was arrived at when only data from the 14th March 1989 onwards were examined – the same time period as that reported in Hobbs *et al.* (1994). The second correlation included all available information from the 21st October 1998 (rainfall events and soil water observations from 1988 are not shown in Figure 7). Similar differences were found for the other three sites between the correlations of Hobbs *et al*. (1994) and those reported here (Table 3).

5.1.1.4.2 Pasture biomass

Pasture biomass runs from the Dbase version of ARIDGROW for the open floodplain and mixed open woodland sites are shown in Figure 8. The resulting model output was markedly different from that shown in Figure 3 of Hobbs *et al*. (1994). The correlations (r^2) between observed and predicted biomass as shown in Figure 8 were 0.16 ($P<0.05$, n=30) for the open floodplain site, and either 0.32 ($P<0.001$, n=40) or 0.36 ($P<0.001$, n=30) for the mixed open woodland site.

The number of biomass observations for the open floodplain site in Figure 3 of Hobbs *et al*. (1994) was 31 whilst only 30 were included in our data set. From inspection of the graph and the data it would appear that an additional observation was made between 22nd May 1990 and 8th June 1990. The mixed open woodland site in Figure 3 of Hobbs *et al.* (1994) showed 30 observations which is the same number as used here for the same time frame (March 1989 - April 1991). However, closer inspection of the two sets of biomass observations for this site showed that the data used in this work also lacked an observation between 22nd May 1990 and 8th June 1990. The observation count was the same as the data used here included an observation on the 18th May 1989.

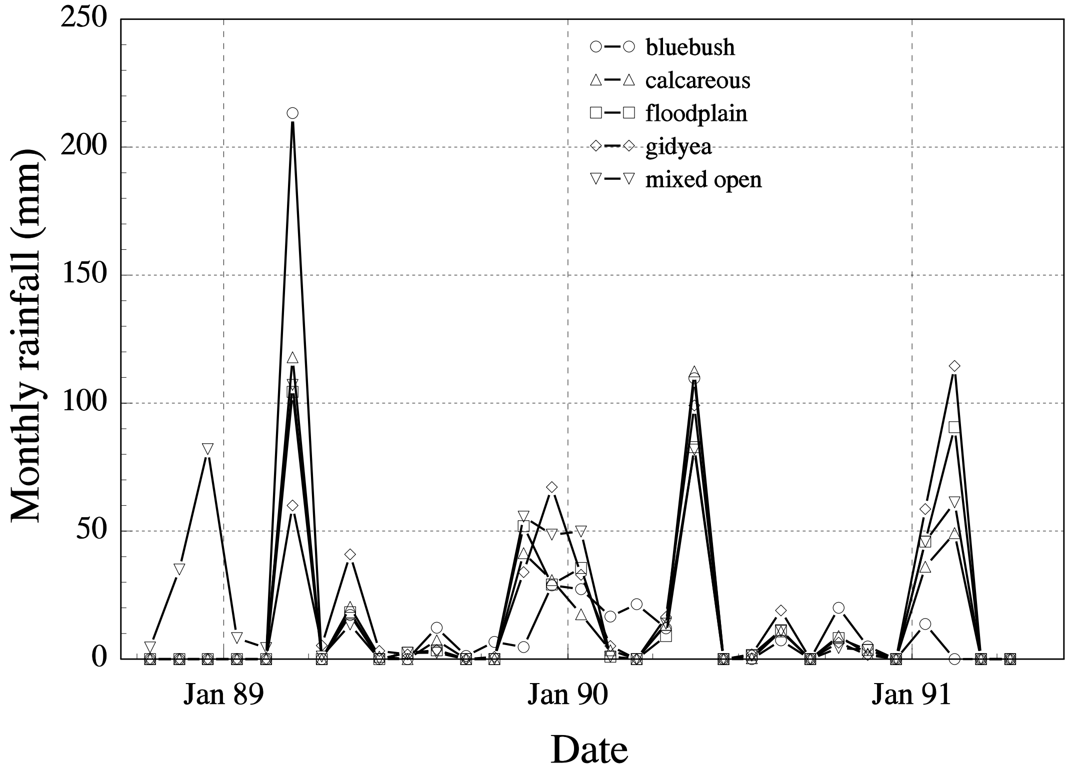

Figure 5. **M**onthly rainfall totals for the five sites in Hobbs *et al*. (1994).

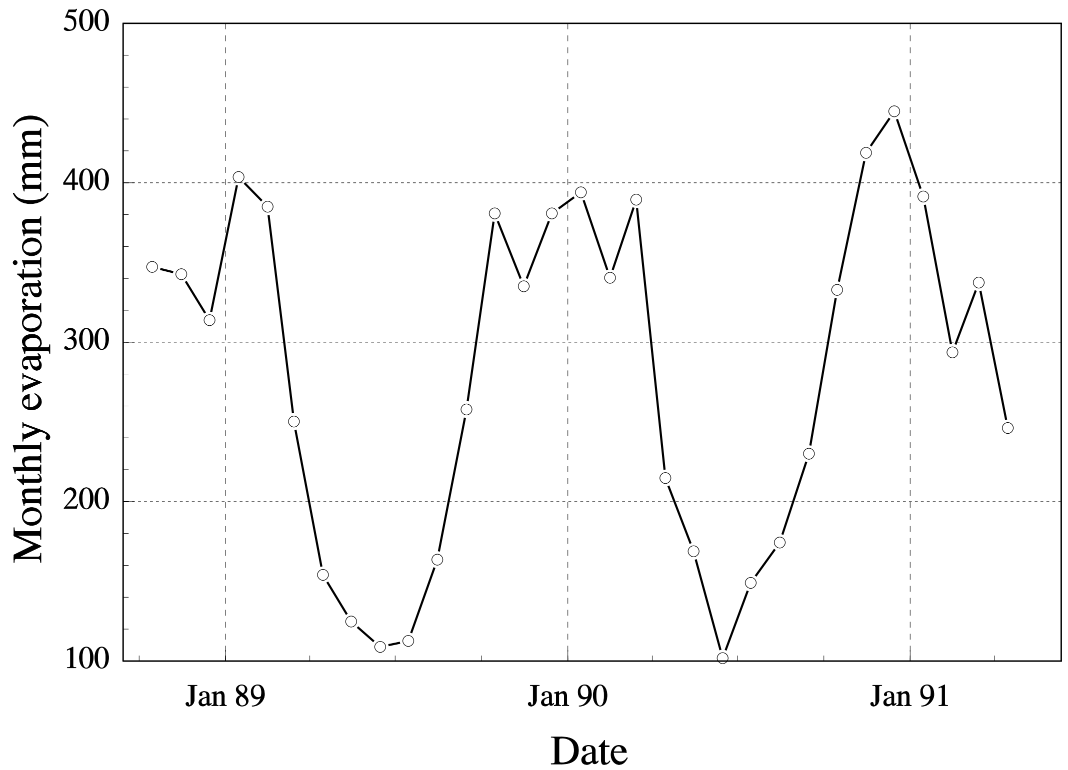

Figure 6. Monthly evaporation totals for Alice Springs as used in Hobbs *et al*. (1994).

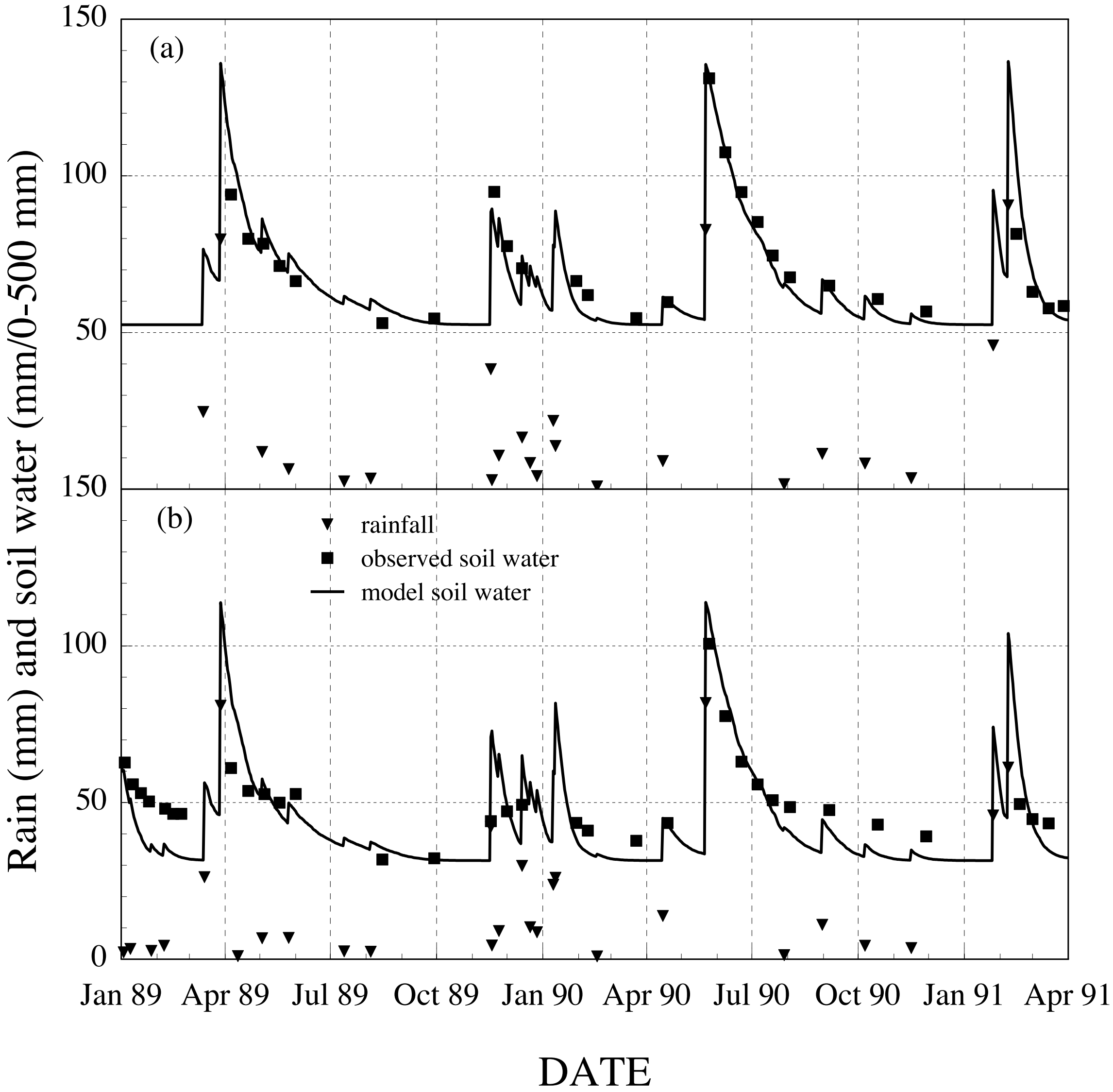

Figure 7. Observed and modelled soil water for the (a) open floodplain and (b) mixed open woodland sites using the Dbase ARIDGROW model.

Table 3. Correlations (r^2) between observed and modelled soil water for all five sites using the Dbase ARIDGROW model. The correlations reported in Hobbs *et al.* (1994) are presented for comparison.

Site	**Correlation** (r^2)[a]		**Number of observations**	**Correlation** from Hobbs *et al.* (1994)
	site specific parameters	central Australia parameters		
Bluebush shrubland	0.861	0.808	28	0.99
Calcareous shrubby grassland	0.805	0.832	30	0.94
Open floodplain	0.878	0.884	27	0.97
Gidyea open woodland	0.891	0.893	29	0.94
Mixed open woodland	0.778[b] 0.709[c]	0.765 0.701	27 36	0.86

[a] all correlations significant at P<0.001.
[b] calculated using same time period as Hobbs *et al.* (1994), March 1989 to April 1991.

[c] calculated using all available rainfall and soil water observations, October 1988 to April 1991.

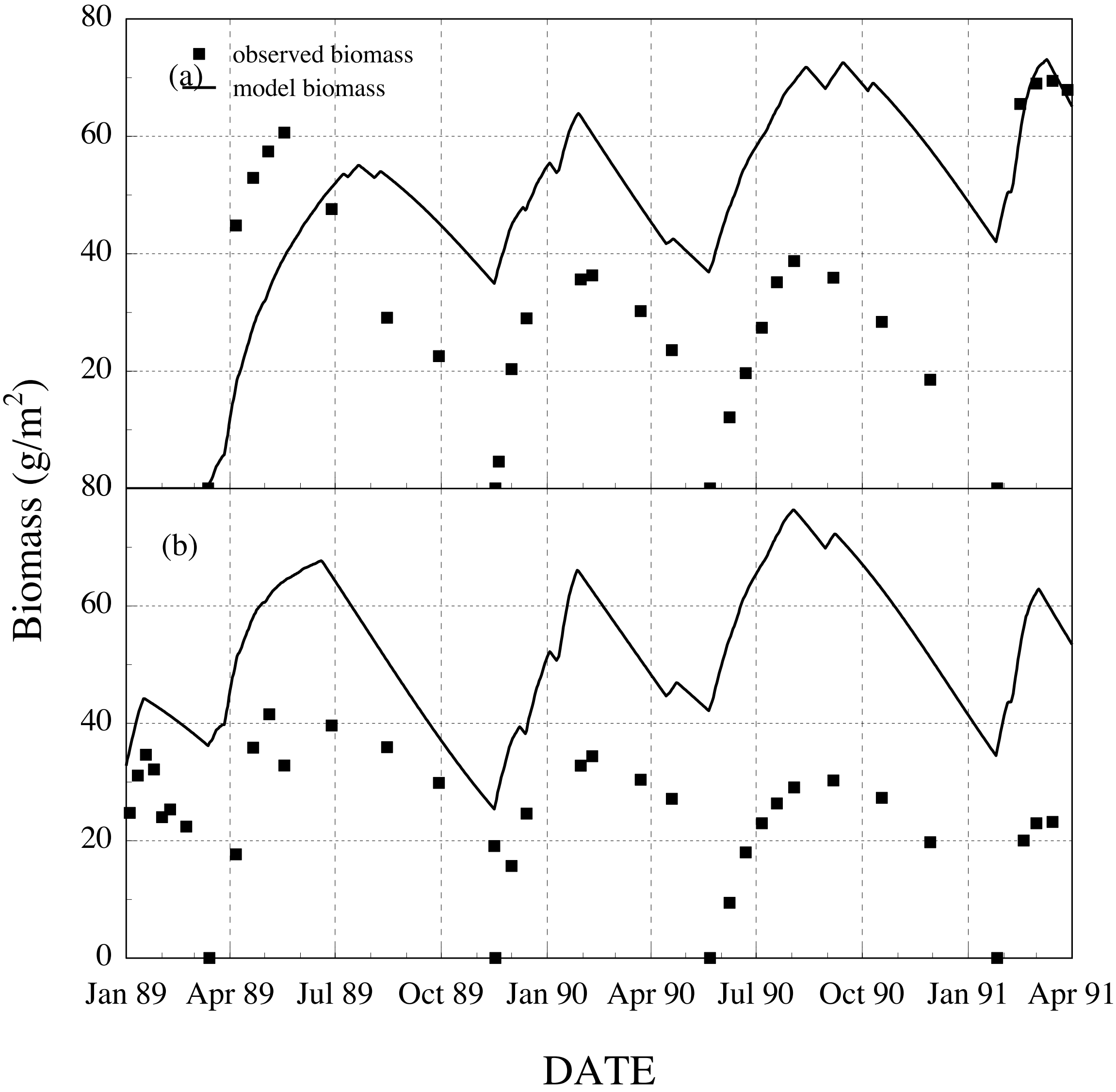

Figure 8. Observed and modelled biomass for the (a) open floodplain and (b) mixed open woodland sites using the Dbase ARIDGROW model.

Inspection of Figure 3 of Hobbs *et al.* (1994) indicated that biomass was reset to zero at the beginning of each growing season. However, the Dbase version of ARIDGROW did not appear to do this calculation automatically. The model code states that total biomass is the sum of the most recent pasture growth event and up to three previous decaying events. Thus the model outputs for all five sites were adjusted on this basis by splitting site 'DBF' files and using a spreadsheet and the correlations recalculated. The results for the open floodplain and mixed open woodland sites are shown in Figure 9. The results were more in line with those presented in Hobbs *et al.* (1994) although not identical. The adjustments to the model biomass are equivalent to assuming that rainfall at the beginning of each growth season resulted in complete knockdown of standing biomass. Thus there was no carryover from one season to the next. Hobbs *et al.* (1994) stated that the results for the open floodplain and mixed open woodland indicated 'that rainfall over about 15 mm increased the rate of herbage decay, with large rainfalls (> 100 mm) resulting in almost complete knockdown and decay of dead herbage within a few days'. The observed and modelled biomass (adjusted) for the other three sites are shown in Figure 10. Correlations for all five sites are presented in Table 4.

5.1.1.4.3 Mean central Australia parameters

Soil moisture and biomass correlation results for all five sites from the use of mean central Australia parameters (Table 2) in the Dbase version of ARIDGROW are shown in Tables 3 and 4. In many cases the mean parameter set gave better results than the site-specific parameters.

5.1.2 Parameterisation of GRASP for central Australia

The ARIDGROW data set (Hobbs 1994, Hobbs *et al.* 1994) provided an opportunity to evaluate both the issues involved in modelling pasture growth in arid environments (<250mm), and how well GRASP handled these issues. The dataset included:

1) 145 observations of TSDM measured at five sites from March 1989 to April 1991, involving 20 'growth pulses', i.e. an average of four growth pulses per site;
2) 151 observations of soil water measured for 0-50 cm, including at least two major wetting and 'dry-down' events at each site; and
3) well documented data analysis and soil and pasture modelling (Hobbs 1994, Hobbs *et al.* 1994).

Thus the ARIDGROW data set has the rare attributes of intensive (fortnightly-monthly) soil water and pasture measurements necessary to model some of the major processes in pasture production in an arid environment.

From the viewpoint of parameterising GRASP the major difficulties in data availability were:

1) lack of daily rainfall (2-4 weekly accumulations were collected);
2) lack of measurements of nitrogen concentration and hence nitrogen uptake;
3) lack of measurement of tree and/or shrub foliage cover;
4) no soil water measurements below 50cm; and
5) a flood plain site with possible run-on contributing to soil moisture.

The following section describes the procedure for addressing the above difficulties.

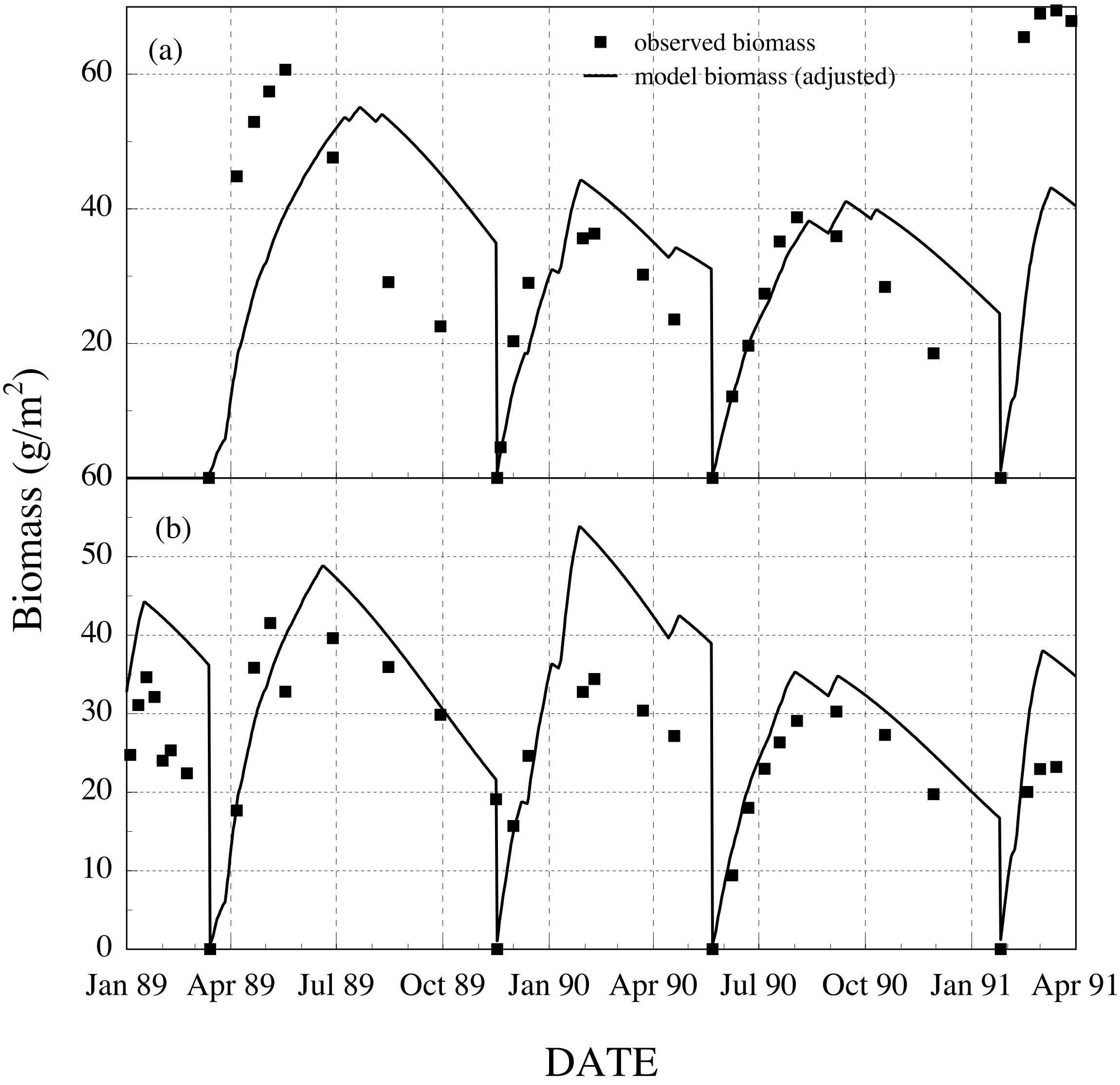

Figure 9. Observed and adjusted model biomass for the (a) open floodplain and (b) mixed open woodland sites using the Dbase ARIDGROW model.

Table 4. Correlations (r^2) between observed and modelled biomass for all five sites using the Dbase ARIDGROW model. The modelled biomass was adjusted assuming that rainfall at the beginning of each growth season resulted in complete knockdown of all biomass.

Site	**Correlation** (r^2)[a]		**Number of observations**
	Site specific parameters	Mean central Australia parameters	
Bluebush shrubland	0.863	0.870	29
Calcareous shrubby grassland	0.532	0.620	32
Open floodplain	0.433	0.650	30
Gidyea open woodland	0.638	0.623	34
Mixed open woodland	0.799[b] 0.797[c]	0.753 0.765	30 40

[a] all correlations significant at P<0.001.
[b] 30 observations between March 1989 and April 1991.
[c] 40 observations between November 1988 and April 1991.

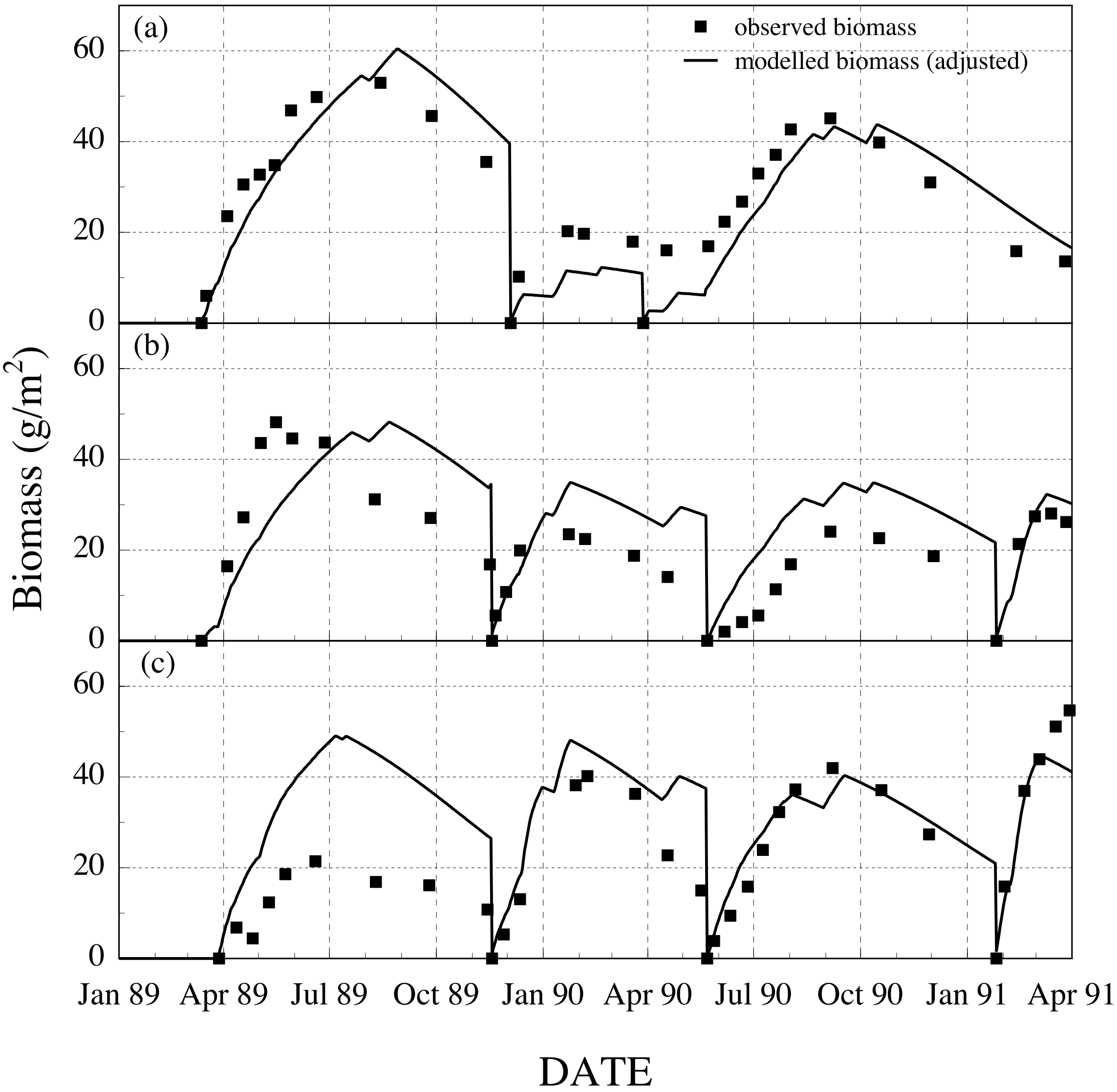

Figure 10. Observed and modelled biomass for the (a) bluebush shrubland, (b) calcareous shrubby grassland and (c) gidyea open woodland sites using the Dbase ARIDGROW model. The modelled biomass was adjusted assuming that rainfall at the beginning of each growth season resulted in complete knockdown of all biomass.

5.1.2.1 Daily rainfall and climate data

With multi-layer soil water models such as GRASP, accumulated rainfall totals are not suitable as input because infiltration to lower layers is strongly affected by rainfall distribution between days. To produce the 'most likely' daily rainfall file, accumulated totals were partitioned using Alice Springs rainfall data (BoM Station 15590) obtained from the Silo database (Beswick *et al.* 1999).

Daily climate files were prepared for each location from the SILO database using climate surfaces described by Jeffrey *et al.* (2001). Inspection of daily data suggested that Class A pan evaporation was likely to be the most unreliable of the climate inputs. A simple and more conservative approach has been developed (McKeon *et al.* 1998) to calculate pan evaporation from solar radiation (SR, estimated from cloud observations) and vapour pressure deficit (VPD). This approach was regarded as less prone to errors associated with: 1) site variability; 2) pan maintenance over time; and 3) rainfall effects. Equations were derived for the central Australia locations and compared to equations derived from 60 locations across Australia's rangelands (Table 5). Daily data were extracted from 1st January 1975 to 31st December 1994 and multiple regressions on SR and VPD derived. For 'dry days' (i.e. zero rainfall up to 9.00 am):

Pan evaporation = -1.109 + 0.2305 * SR + 0.1826 * VPD (n = 13,740; r^2 = 0.748)

The equation was similar to that derived from 60 locations in Australia's rangelands:

Pan evaporation = -1.378 + 0.2180 * SR + 0.1647 * VPD (n = 25,280; r^2 = 0.801)

Table 5. Multiple regressions for daily Class A Pan Evaporation derived for: 1) stations in Queensland (Emerald, Gayndah, Charleville, Charters Towers, Julia Creek); 2) 60 locations in Australia's rangelands; and 3) five sites in central Australia. All data from SILO database using the daily surfaces of Jeffrey *et al*. (2001).

Data source		**Number of days**	**r^2**	**Equation**
Five stations in Queensland				y = -0.481 + 0.1637 * SR + 0.1694 * VPD
Sixty rangeland locations: 1975 to 1994	All days	29,280	0.792	y = -1.007 + 0.2041 * SR + 0.1637 * VPD
	Dry days, i.e. zero rain up to 9.00am	25,200	0.801	y = -1.378 + 0.2180 * SR + 0.1647 * VPD
	Rain days >0 rain up to 9.00 am (actually 'day after rain')	4,080	0.696	y = 0.073 + 0.1569 * SR + 0.1710 * VPD
Central Australia: 1987 to 1994	All days	14,610	0.750	y = -0.865 + 0.2208 * SR + 0.1829 * VPD
	'dry' days	13,740	0.748	y = -1.109 + 0.2305 * SR + 0.1826 * VPD
	'day after rain' days	870	0.771	Y = 0.606 + 0.1551 * SR + 0.2004 * VPD

5.1.2.2 Site attributes

All sites had some shrub/tree cover (Table 6). Thus estimates of available soil water for layers 3 and 4 (50–100 cm and below 100 cm respectively) were required to correctly partition ET between soil layers. Assuming that the soils were relatively uniform, available soil water range values (mm per 10 cm, Table 6) for layer 2 (10-50 cm) were used for layer 3 (50-100 cm). Values for layer 4 (below 100 cm) were estimated based on experience from other sites in northern Australia and relative depths derived from discussions with T. Hobbs and M. Stafford Smith.

Foliage projected cover (FPC) and tree basal area (TBA) were derived from estimates (Hobbs 1994) and subsequent discussions with T. Hobbs. FPC was converted to TBA using a factor of 2 following work of Hassett *et al*. (2001). Potential nitrogen uptake values were derived as part of the stepwise parameterisation procedure described in detail later.

Table 6. Location, landscape type, landform, dominant trees and shrubs, and predominant herbage species of the five study sites in central Australia (Hobbs 1994, Hobbs *et al*. 1994) and parameters used in GRASP.

Location	**Landscape**	**Landform/ Soil Texture**	**Trees & Shrubs**	**Herbage**	**Tree/ shrub FPC (%)**	**TBA (m^2/ha)**	**Available water mm per 10 cm**			**Total available water 0-100 cm (mm)**	**Trees & shrubs**		**Maximum N uptake per growth pulse (kg N/ha)**	**Potential regrowth (kg DM/ha/ day)**	**Yield at 50% 'cover' (kg DM/ha)**	**ARID-GROW evap. constant 'k' (Hobbs *et al.* 1994)**
							0-10 cm	10-50 cm	50-100 cm		Rooting depth (m)	Avail. water layer 4 (mm)				
Site 1 25° 00'S 133° 12'E	Bluebush shrubland	Gentle erosional slopes/silty clay loam	*Maireana astrotricha* (6% cover)	*Maireana carnosa* *Enneapogon cylindricus* *Helichrysum ayersii* *Helipterum charsleyae* *Enneapogon avenaceus*	3	1.5	22	16.3	16	167	1.0	0	5.0	25	1500	3.5
Site 2 23° 59'S 133° 49'E	Calcareous shrubby grassland	Undulating limestone hills and rises/loam	*Acacia kempeana* (1% cover)	*Enneapogon cylindricus* *Enneapogon avenaceus* *Helipterum floribundum* *Sida* spp. *Tripogon lolliformis*	1	0.5	17	13.5	14	141	1.0	0	4.5	20	1500	6.1
Site 3 23° 34'S 133° 36'E	Open floodplain	Flat drainage floors and floodouts/sandy clay loam	*Maireana aphylla* *Sclerolaena bicornis* (2% cover)	*Sclerolaena costata* *Tripogon lolliformis* *Indigofera linnaei* *Maireana scleroptera* *Sida* spp.	1.5	0.75	25	15	16	165	3.0	320	6.5	25	1000	7.3
Site 4 23° 50'S 134° 45'E	Gidyea open woodland	Slightly dissected alluvial plains/silty clay loam	*Acacia georginae* (4% cover)	*Tribulus terrestris* *Stenopetalum nutans* *Salsola kali* *Enteropogon acicularis* *Fimbristylis dichotoma*	4	2	13	14.0	14	139	1.5	50	5.0	25	600	8.9
Site 5 23° 34'S 133° 34'E	Mixed open woodland	Flat plains/sandy loam	*Atalaya hemiglauca* *Acacia aneura* *Ventilago viminalis* (6% cover)	*Tripogon lolliformis* *Sclerolaena costata* *Enteropogon acicularis* *Salsola kali* *Digitaria coenicola*	4	2	19	17.3	17	173	2.0	170	4.0	25	600	8.0
Average values					**2.7**	**1.35**	**19.2**	**15.2**	**15.4**	**157**	**1.7**	**108**	**5**	**24**	**1040**	**6.8**

Table 7. Comparison of observed and predicted TSDM correlations (r^2) for five sites in central Australia. Study 1 was a re-programmed version of ARIDGROW with yields reset at the start of each growth pulse. Study 2 was the GRASP model (version GVT89C08) with exactly the same observations and resets as used in Study 1. In Study 3, a new subroutine was added to GRASP to simulate the start of growth pulses by resetting nitrogen availability and standing dead and litter pools. Reset observations were removed for comparison with the previous version of GRASP. Subscripts are as follows: (a) Root Mean Square; (b) number of growth pulses; (c) potential nitrogen uptake (kg N/ha).

	Study 1			**Study 2**				**Study 3**					
	ARIDGROW			**GRASP: Yield reset with each growth pulse**				**GRASP: N pulse model Reset and yields removed**				**Reset yields removed**	
	No. of observations	Site specific parameters	Central Australia parameters	Original calcareous parameters [1] (McKeon *et al*. 1996)	Site specific parameters Peak TSDM[2]	Site specific parameters [3]	Average central Australian parameters [4]	No. of observations	Site specific parameters [5]	Average parameters [6] N=5[c]	Average parameters [7] N=15[c]	Site specific parameters [8]	Average parameters [9]
Calcareous	32	0.532	0.620	0.860 62[a]	0.639 76[a] (4)[b]	0.754 92[a]	0.751 89[a]	28	0.600 134[a]	0.666 110[a]	0.725 122[a]	0.649 99[a]	0.645 95[a]
Gidyea	34	0.638	0.623	0.248 151[a]	0.726 75[a] (4)[b]	0.679 100[a]	0.706 96[a]	30	0.568 107[a]	0.832 95[a]	0.840 98[a]	0.576 106[a]	0.614 102[a]
Bluebush	29	0.863	0.870	0.628 111[a]	0.864 93[a] (3)[b]	0.797 81[a]	0.797 77[a]	26	0.567 107[a]	0.584 93[a]	0.609 125[a]	0.688 86[a]	0.714 82[a]
Mixed open woodland	40	0.797	0.765	0.553 102[a]	0.667 44[a] (5)[b]	0.860 53[a]	0.852 56[a]	35	0.646 89[a]	0.627 95[a]	0.635 102[a]	0.694 57[a]	0.679 60[a]
Floodplain	30	0.433	0.650	0.578 151[a]	0.745 180[a] (4)[b]	0.718 133[a]	0.720 150[a]	26	0.624 132[a]	0.706 136[a]	0.679 136[a]	0.562 143[a]	0.564 161[a]
Floodplain as run-on	30	0.433	0.650	0.539 150[a]	0.939 53[a] (4)[b]	0.711 123[a]	0.748 122[a]	26	0.618 126[a]	0.697 113[a]	0.634 112[a]	0.566 133[a]	0.603 132[a]
All 5 sites with floodplain as run-on	165				0.810 60[a] (20)[b]	0.747 90[a]	0.717 88[a]	145	0.597 111[a]	0.607 100[a]	0.621 110[a]	0.631 96[a]	0.587 94[a]

'mrx' files used in the generation of data presented here and throughout the text are listed for completeness and to facilitate later work: [1]AGCA_2.mrx, [2]AGCA_MA5.mrx, [3]AGCA_5.mrx, [4]AGCA_5AV.mrx, [5]AGCA_5NR.mrx, [6]AGCA_5AN.mrx, [7]AGCA_515.mrx, [8]AGCA_5.mrx, [9]AGAC_5AV.mrx.

5.1.2.2.1 Floodplain site

The 'open floodplain' site appeared to include the influence of run-on as additional moisture. The following approach has been developed with GRASP to simulate known run-on sites assuming that 50% of the landscape contributes run-on to the other 50%. In Step 1, run-off is simulated using GRASP run-off model parameters (Scanlan *et al.* 1996). Daily run-off is added to daily rainfall and, in Step 2, the site is simulated as site without run-off, i.e. only through drainage. The floodplain site is assumed to represent only the run-on component of th\e landscape. This approach allows greater infiltration of water to lower layers. Evidence from soil moisture measurements at one such site (Kidman Springs, L. Cafe unpublished data) indicated that extraction by plants occurs from the 50-100 cm layer in a similar way to the 10-50 cm layer. The relevant GRASP parameter (p106) was adjusted appropriately to reflect the likely greater depth of moisture extraction. As will be described later, these changes to input rainfall and site parameters resulted in a better simulation of observed soil water and TSDM (Table 7).

5.1.2.1 Parameterisation procedure

5.1.2.1.1 Base run

An initial parameter set was derived from the simulations reported by McKeon *et al.* (1996). This parameter set followed the view of Hobbs *et al.* 1994 of considering only the top 50 cm of soil and not including the effects of tree/shrub cover. Input rainfall data included accumulated values. A rapid detachment rate associated with rainfall was developed from the observation that little carryover of standing dead occurred from 'growth pulse' to 'growth pulse' as described above. Plant growth parameters in the initial run were developed by calibration on one site, i.e. Site 2 'calcareous'. The other sites were then used as 'quasi' independent validation ('quasi' because data were collected over same time period). Whilst the resultant parameter set provided a good fit for the calcareous data, other sites were not as well simulated as by ARIDGROW (McKeon *et al.* 1996 and Table 7).

5.1.2.1.2 Available water range

Soil water parameters were estimated for each site as described above. Upper limits of soil water were derived from the addition of highest soil-water measurement and simulated ET between the time of rainfall event and measurement of soil water.

5.1.2.1.3 Potential soil evaporation

Potential soil evaporation (p033) was taken as 4 mm/day for all sites except 'bluebush'. At the bluebush site measured soil water during the two 'dry-down' phases indicated slow rates of ET. Hence, Hobbs *et al.* (1994) found that the site extraction co-efficient, the 'evaporative co-efficient' in ARIDGROW, was substantially lower for this site than the other four sites. This may reflect the higher silt content at this site (Table 6) that can result in lower soil evaporation rates. For the bluebush site potential soil evaporation was set to a low value (0.5 mm/day).

5.1.2.1.4 Potential transpiration and sward height

The effect of low sward height on increasing potential transpiration was not included as we hypothesised that, in this arid climate, the advective effect of bare soil on potential transpiration was already included in measured Class A pan evaporation. This view is supported by the higher sensitivity of Class A pan evaporation to VPD in central Australia compared to more humid climates (Table 6).

5.1.2.1.5 Potential transpiration and yield

Potential transpiration from pasture was calculated as a function of green pasture biomass and was parameterised as the 'yield that gives 50% of potential ET' (p045). The parameter has usually been derived from the measured relationship between projected green cover and green yield, however, data were not available for the central Australian sites. Initial simulations were conducted with p045 set to values (600 kg DM/ha) found for similar annual/forb vegetation in northern Australia (K.A. Day pers. comm.). Comparison with 'dry-down' phases for several sites (calcareous, bluebush, floodplain) indicated that higher values of p045 gave better agreement with measured soil water. The values of p045 followed the same trend across sites as the 'evaporative constant' used in ARIDGROW (Table 6). However, in GRASP p045 is a parameter of vegetation rather than soils. Further field work would be required to determine whether independent derivation of P045 from vegetation attributes was possible.

5.1.2.1.6 Potential regrowth rate

Plant density was set as a constant assuming a constant seed bank density. An average potential regrowth rate was derived for each site by comparing simulated and the observed peak yields for each growth pulse.

Potential regrowth rate (PRGR, kg DM/ha) was calculated for each growth pulse from peak TSDM and simulated growth index (GI) accumulated from the start of each growth pulse:

$$\text{PRGR} = \frac{\text{peak TSDM}}{\sum \text{GI}}$$

Potential regrowth rate was not constant at each site and there was as much variation between growth pulses as between sites. Exploration of sources of variation indicated trends (Figure 11) with simulated nitrogen content of dry matter (%) suggesting a strong effect of nitrogen nutrition (Mott *et al*. 1985). Thus PRGR was set at the maximum value of 25 kg DM/ha/day and nitrogen limitation included. The value of 25 kg DM/ha/day was as the high end of PRGR values found at other sites (K.A. Day pers. comm.) across northern Australia but was consistent with the values used by Mott *et al*. (1985) as a potential growth rate.

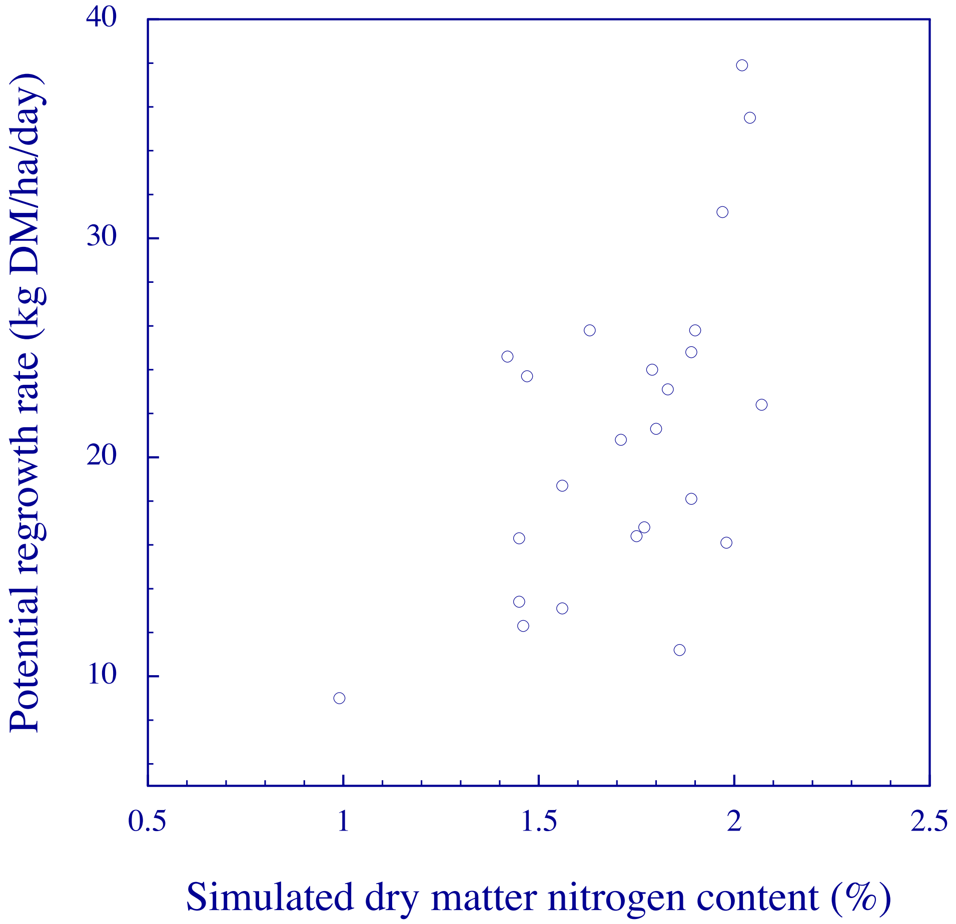

Figure 11. Relationship between dry matter simulated nitrogen content (%) and potential regrowth rate (kg DM/ha/day).

5.1.2.1.7 Nitrogen availability and critical nitrogen concentration

Nitrogen concentration (and uptake) was not measured at the central Australian sites. From work at other arid zone sites (I. Watson pers. comm., M. Friedel pers. comm.) the critical nitrogen concentration of the sward at which growth stops (% N, p101) was estimated at 0.88%. K.A. Day (pers. comm.) reported values of 0.8% N for annual/forb sites in northern Australia whilst Christie (1975) found low growth at 1.2% N for C_3 mulga grasses. A value of 0.88% N was used with the observed peak yields to estimate the parameters: 1) 'potential N uptake'; and 2) 'rate of N uptake per mm of transpiration' for each site (Table 5). The concentration at which nitrogen limitation on growth begins was estimated at 1.5% N based on the data in Figure 11 and on other studies with C_3 species (Christie 1975).

The importance of nitrogen availability was evaluated by increasing values from the average value of 5 to 15 kg N/ha for all sites. Simulations indicated that yields were limited by potential N uptake at only one site (bluebush). Thus, compared to potential nitrogen availability, water limitation exerted stronger effects through direct effects on the growth index and indirectly through nitrogen uptake and nitrogen concentration.

5.1.2.1.8 Senescence

Measurements of green and dead biomass were not taken. Parameters used to describe the effect of water stress on death were those found at northern Australian sites (K.A. Day pers. comm.). Of particular importance was the 'soil water index required for 100% cover' (p009) that was set to 0.15 based on that derived for annual vegetation (Antrim Red Earth, K.A. Day pers. comm.). More detailed consideration of moisture extraction at the end of drying down phases and examination of site photographs would be required to improve this parameterisation. The vegetation was assumed to be unaffected by frost.

5.1.2.1.9 Detachment rates

The rates of detachment (0.005 kg/kg/day) reported by Hobbs *et al*. 1994 were used although there was considerable variation between growth pulses (Figures 9 and 10) Hobbs *et al*. (1994) reported that dead material disappeared rapidly because of rainfall and hence TSDM was reset to zero at the start of each growth pulse as described above in Section 5.1.1.4.2. Based on these observations, relationships were included in GRASP to substantially increase the rate of detachment with rainfall (McKeon *et al*. 1996). Parameters were derived by calibration to observed yields. However, as the input rainfall files used in the 1996 study included accumulated totals this work was re-evaluated here. Potential litter breakdown rate was set higher (0.08 kg/kg/day) to account for the more fragile tissue associated with annual/ephemeral vegetation. However, no litter observations were available to compare with simulations.

5.1.2.1.10 Summary of parameterisation procedure

The approach described above resulted in the determination of as many parameters as possible from measurements, site description and experience from other sites in northern Australia (e.g. K.A. Day). Thus for four of the five sites, only two parameters ('potential regrowth rate' and 'yield at 50% potential transpiration') were calibrated to account for site differences. For the Bluebush site 'potential soil evaporation' and 'potential nitrogen uptake' were also calibrated to accurately simulate soil water and TSDM.

The calibration procedure was iterative in which the growth and transpiration parameters were manually adjusted to achieve agreement with both soil water and TSDM data. A formal optimisation procedure could have been used but as only two parameters were involved but a manual procedure was regarded as adequate for this study.

5.1.2.2 Simulation studies

Several simulation steps were repeated examining model parameters in terms of different sets of observations (file names have been included for documentation and cross reference to Table 7).

1) peak growth yield with TSDM reset to zero at the start of each pulse and different site parameters (AGCA_MA5.mrx);
2) all TSDM values with TSDM reset with different site parameters (AGCA_5.mrx);
3) all TSDM values with TSDM reset and with average parameters (AGCA_5AV.mrx);
4) steps 2 and 3 repeated but with TSDM values associated with reset yield at start of growth pulses removed and a new start-of-growth pulse included in GRASP (AGCA_5NR.mrx, AGCA_5AN.mrx);
5) sensitivity test of new growth pulse model with different values of potential nitrogen uptake (AGCA_5AN.mrx and AGCA_515.mrx); and
6) hundred year simulation with subjective validation test based on observations and grazier observations (AGCA_5SI.mrx).

5.1.2.2.1 Simulation of soil water

Figures 12a-e show the time series of observed and simulated soil water for the 0-50 cm soil layer. The model accounted for a high proportion of variation (r^2 from 0.76 to 0.89, Table 8). For four of the five sites, root mean square (RMS) values were low (6-8 mm) compared to typical values for other sites (Day *et al*. 1997), probably reflecting the high quality of measured data with lower sampling variability than occurs with other forms of soil moisture measurement. The RMS for Bluebush was higher (10.7 mm) reflecting the difficulty in simulating the lower rates of ET measured at this site. For the 14 major drying down phases across the five sites, the rate of drying towards the end of the drying phase was overestimated on six occasions. However, the other eight were reasonably well simulated.

When average soil moisture, transpiration and shrub/tree parameters were used, similar high r^2 values (0.760 to 0.891) and low RMS values (5.7 to 10.0 mm) resulted. However, as expected, the Bluebush site had a lower simulated mean soil water (70 mm) compared to the observed mean of (77 mm). Nevertheless the average parameters provide an adequate simulation of soil water at half the sites as indicated by higher r^2, lower RMS and slopes closer to one (Table 8). Correlation (r^2) and RMS values for the 'run-on' site simulation indicated that the approach adopted for this site provide a simulation in better agreement with observed data (Figure 13).

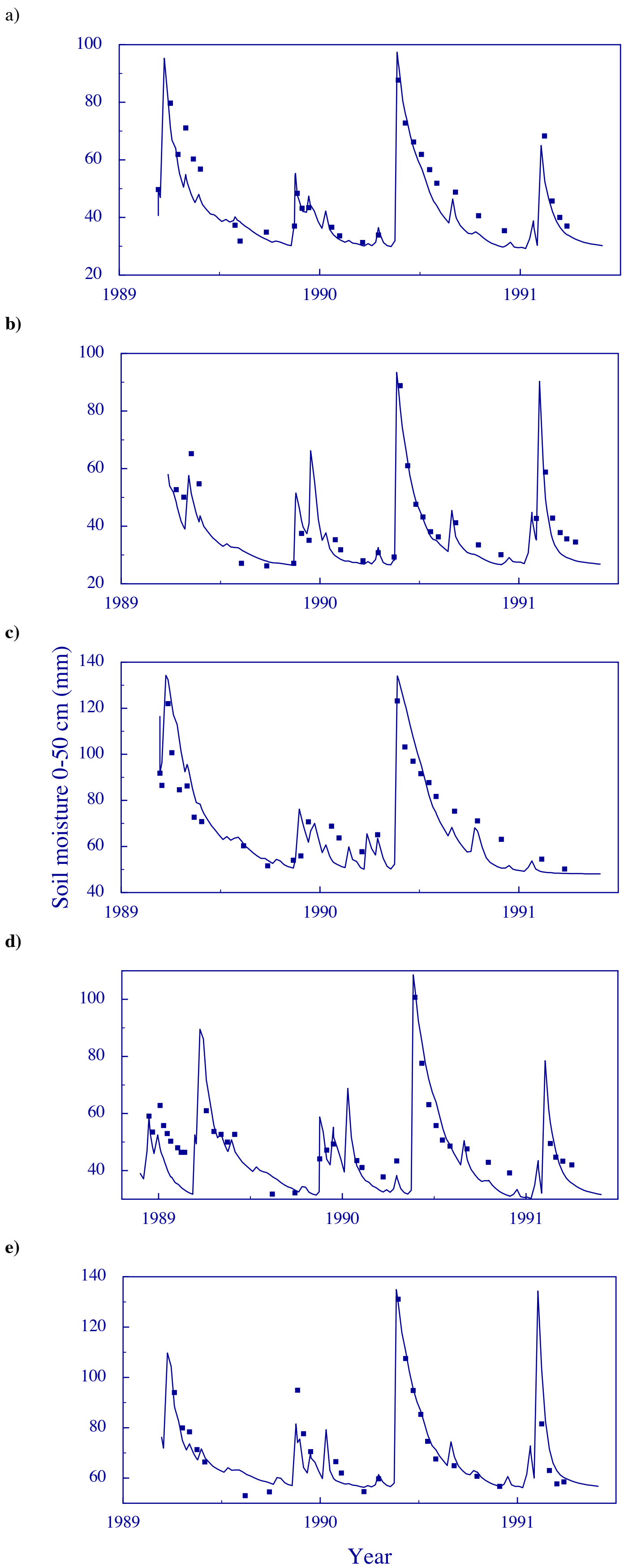

Figure 12. Time series of observed and predicted soil moisture (0-50 cm) for the various sites: a) calcareous; b) gidyea; c) bluebush; d) mixed open woodland; and e) floodplain.

Table 8. Comparison of observed and simulated soil moisture (0-50 cm) for the five sites in central Australia using site-specific parameters and average central Australian parameters. Results using the average central Australian parameters are shown in italics.

Site	Number of observations	Observed mean (mm)	Simulated mean (mm)	r^2	Regression X = observed		Root mean square
					Slope	Intercept	
Calcareous	31	51	47 *48*	0.869 *0.849*	0.87 *0.96*	+ 2.8 *- 1.0*	6.9 *7.3*
Gidyea	29	41	38 *42*	0.865 *0.855*	0.81 *0.96*	+ 4.5 *+ 2.2*	6.2 *5.7*
Bluebush	28	77	79 *70*	0.887 *0.891*	1.27 *0.98*	-18.6 *- 5.5*	10.7 *10.0*
Mixed open woodland	36	51	49 *47*	0.764 *0.760*	1.10 *1.03*	- 7.0 *- 4.7*	7.9 *7.9*
Floodplain	27	74	74 *74*	0.837 *0.855*	0.90 *0.85*	+ 7.7 *+ 11.4*	7.5 *7.0*
Floodplain as 'run-on'	27	74	76 *75*	0.875 *0.891*	0.98 *0.90*	+ 3.3 *+ 9.2*	7.2 *6.3*

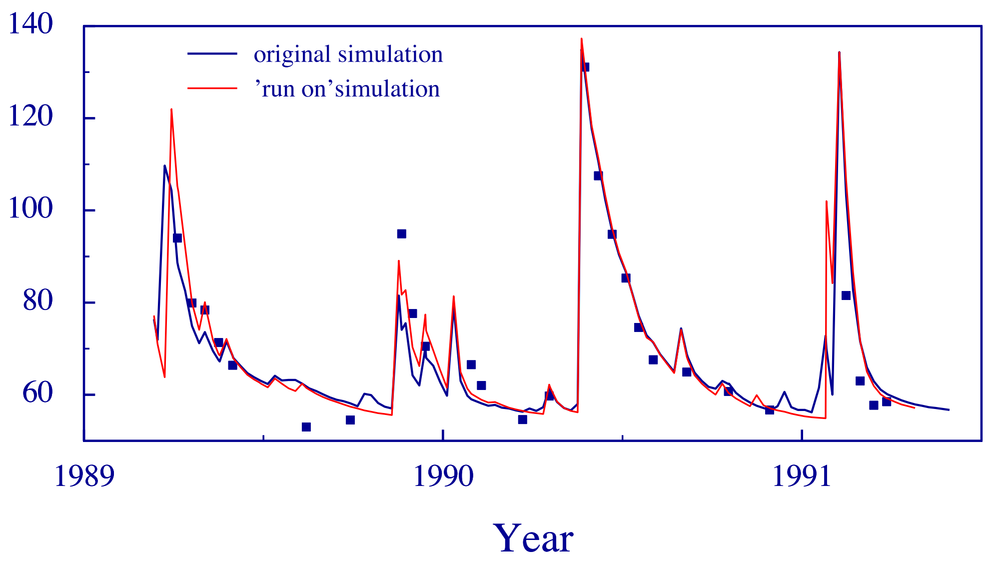

Figure 13. Time series of observed and predicted soil moisture (0-50 cm) for the floodplain site with and without 'run on'.

5.1.2.2.2 Peak yield and pasture growth rate

Pasture growth rate was calculated for each growth pulse from the reset date (after rainfall) to peak yield. Values were compared with input climatic and simulated variables (Table 9). Rainfall during the growing period explained a high proportion of variation (r^2 = 0.752) and not unexpectedly derived variables with site specific parameters such as growth index, ET, transpiration and simulated growth also explained a high proportion of variation (r^2 = 0.654; 0.878; 0.794; and 0.910 respectively). When average parameters (Table 6) were used, derived variables (e.g. ET) had r^2 slightly lower than rainfall alone (r^2 = 0.72 to 0.73). Simulated growth with average parameters explained 75 to 80% of the variation for low and high nitrogen availability. The results reflect the expected dominating influencing of rainfall on pasture growth and arid environments. The issues of the (1) need for more complex modelling (than just a simple regression on rainfall, e.g. Table 9); and (2) the importance of nutrient limitation will be discussed later.

Over the 20 growth pulses the model explained a high degree of variation in peak TSDM (r^2 = 0.810) although for individual sites r^2 were generally lower (Table 7).

For over 100 native pasture sites in Queensland, Day *et al*. (1997) evaluated the capability of GRASP to simulate peak TSDM for data that had not been included in the parameterisation process. They found that whilst the model accounted for 90% of variation in peak TSDM where data was used in the calibration process, a lower proportion of variation in subsequent peak TSDM was accounted for (70-80%). The results reported here with the average parameter set are consistent with the findings of Day *et al*. (1997).

Time series of simulated pasture TSDM indicated that the model agreed well in the timing of peak yield. However, there were three pulses that were over estimated by 100 kg DM/ha. In the case of the 'Gidyea' site, the observed data suggested peak yield increased over time across the four growth pulses whilst the model simulated similar peak yields for each pulse. The analysis with ARIDGROW found similar patterns of simulated growth to that of GRASP (Figures 10 and 12).

Since the model accurately simulated soil water and, as a consequence, the length of the growth pulse, other factors need to be considered to further explain variation in peak TSDM, e.g. species composition, size of initial seedling pool and/or variable nutrient availability. These factors are outside the current range of this study but could be examined with the use of other models, e.g. germination/establishment (Menke *et al.* 1999).

Table 9. Regressions between average daily growth rate calculated from the start of growth pulse to peak TSDM, and measured and simulated variables for 20 growth pulses (across five sites[a]).

Variable	Correlation (r^2)	Equation
Days	0.268	y = 8.8 - 0.044 * x
VPD	0.020	y = 4.5 + 0.033 * x
Rainfall	0.752	y = 1.97 + 3.03 * x
ET	0.878	y = 0.08 + 4.55 * x
Transpiration	0.794	y = 2.85 + 5.50 * x
Radiation interception	0.490	y = 2.37 + 0.97 * x
Simulated growth index	0.654	y = 0.52 + 16.6 * x
Simulated growth[b]	0.910	y = -0.43 + 1.00 * x
Simulated growth with average parameters (potential N = 5 kg/ha)	0.748	y = - 0.84 + 1.16 * x
Simulated growth with average parameters (potential N = 15 kg/ha)	0.800	y = - 0.57 + 1.07 * x

[a] the floodplain site was represented by the 'run-on' parameterisation which include likely additional 'rainfall' in the form of 'run-on'.
[b] simulated growth included nitrogen limitations (Table 7).

5.1.2.2.3 Peak yield with yield reset

Table 7 shows the comparison of model and observed data for all yields using site specific and average parameters. TSDM was reset at the start of each growth pulse. Both parameter sets explained a high proportion of variation at each site (r^2 from 0.68 to 0.86) reflecting the model's ability to simulate growth pulses. The worst site was Gidyea because of the model's inability to account for variation in size of growth pulses over time. When compared to ARIDGROW, GRASP with both the site-specific parameters and averaged parameters explained a higher proportion of variation at four of the five sites. ARIDGROW better simulated the Bluebush site with both site-specific and average parameter sets.

5.1.2.2.4 Peak yield without yield reset

Simulation of TSDM without yield resetting required resolution of two issues: 1) resetting nitrogen availability; and 2) rapid detachment and decomposition at the start of growth pulses.

In GRASP, yield reset at the start of a growth pulse also resets nitrogen availability. In simulations where the yield is not reset (e.g. over hundred years), nitrogen availability is reset once a year (e.g. 1 October). This approach has allowed reasonable simulation in environments with reliable seasonality of growth. For example in tropical grasslands temperature and moisture limit winter/dry season growth resulting in a distinct summer growing season. In particular this approach accurately represents the limitation of nitrogen that occurs in autumn/late wet season (e.g. Day *et al.* 1997). Conversely in southern Australian temperate pastures, higher temperatures and low rainfall in summer lead to a distinct autumn/winter/spring growing season. However, such an approach (i.e. annual resetting) may not be applicable to arid environments where frequent severe dry periods provide suitable pre-conditions for rapid mineralisation of nitrogen during subsequent growth pulses (Mott *et al.* 1985). The field measurements by Hobbs *et al.* (1994) indicated an average of four growth pulses per site over two years. Hence an annual reset would appear inappropriate. As a result, further model development was conducted to simulate variable growth pulses. Nitrogen availability was reset if the following sequential conditions had occurred: 1) 0-50 cm soil layer had dried to below 10% of available water (i.e. pre-conditions for rapid mineralisation); and then 2) when the soil water index subsequently exceeded 0.80 (i.e. start of a growth pulse). At this time standing dead and litter were set to zero to simulate rapid decay of dead tissue. Residual standing green material was not reset but carried over to next growth pulse. Evaluation of simulations over 100 years indicated an average of three growth pulses per year although during wetter periods, e.g. early 1970s, fewer pulses were simulated because good rainfall conditions prevented the soil from drying to low levels.

Table 7 compares parameter sets where reset yields have been removed (reducing number of observations) and the arid-growth pulse model. The removal of observations of low yield at the start of growth pulse reduced r^2 value (0.50 to 0.60 compared to 0.70 - 0.80). The arid-growth pulse model gave similar or in some cases improved explanation of variation suggesting that some of the starting 'reset' yields may have over-estimated the decline in TSDM associated with start of the growth pulse.

5.1.3 Discussion

5.1.3.1 Model complexity

The high correlation ($r^2 = 0.75$) between rainfall (or simulated ET) and measured plant growth prompts the question of what advantage is gained by parameterising a more complex model such as GRASP to achieve a similar explanation of variation.

More complex models such as GRASP provide several advantages over simpler approaches:

1) extrapolation in time (e.g. last 100 years) and space (soils, tree cover) is a logical extension of the processes that have been included;

2) output is daily allowing links to management models (e.g. Stafford Smith and McKeon 1998, Stafford Smith *et al*. 2000); and

3) other outputs (green cover) are provided that can be compared with other measurement techniques over longer time periods (NDVI, Carter *et al*. 2000) allowing a greater range of climatic and environmental variation to be tested.

However, on the other hand, the complexity of models such as GRASP means that:

1) many of the processes can not be validated at a particular location and parameterisations from other locations have to be used; and
2) the model is a 'black box' to most users.

Johnston (1996) developed a compromise between these arguments for his application of calculating safe carrying capacity on individual properties. He calibrated GRASP for his sites that had only a few growth pulses and then used simulations with GRASP over 30 years of historical climate data to establish simple regression with rainfall and location attributes. This simplifying approach provided: 1) the confidence that rainfall use efficiencies were not biased by rainfall distribution during the necessarily limited time of field measurement; and 2) appropriate output for use in explaining the calculation procedure to clients (e.g. graziers).

The results show that GRASP can be parameterised to simulate the variation in above-ground pasture and soil water over time and across sites. Appropriately parameterised, GRASP was able to simulate as well as ARIDGROW and hence is a useful replacement for ARIDGROW in terms of future Aussie GRASS goals, i.e. simulation of pasture growth for the whole continent within the one modelling framework.

A major finding in applying GRASP to arid environments was the need to address the issue of growth pulses rather than reliable growing seasons. Further research on the processes associated with the start of growth pulse (rapid disappearance, nitrogen mineralisation) is required in terms of longer time series of vegetation response (e.g. remote sensing) and application to other sites in Australian rangelands.

5.2 Western Australia

5.2.1 IMAGES

5.2.1.1 Introduction

The IMAGES model was tested using two sets of data: 1) Boolathana grazing trial in WA; and 2) Roshier experimental work in NSW. The main effort was focussed on the Boolathana data and a comprehensive report on this work has been produced as a separate publication (Watson 1999). As such, a summary of Watson's (1999) findings follow and this report will concentrate on the work involving the Roshier data.

5.2.1.2 Findings from the Boolathana grazing trial simulations

5.2.1.2.1 Results summary

The IMAGES model was run for good and poor condition sites, on duplex and sandy soil types at very high and very low stocking rates (i.e. 2 x 2 x 2 = 8 treatments). For each soil type, the model was parameterised for good condition and very low stocking rate. This parameter set was then used for the other three combinations, i.e. poor condition - very low stocking rate, and very high stocking rates in good and poor condition. The upper limits for shrub density and shrub and herbage biomass had to be adjusted for poor condition in each soil type to provide realistic outputs.

IMAGES did not model observed shrub dynamics well. But, shrubs are contrary beasts. Mortality can be predicted with some accuracy. However, recruitment was highly unpredictable, even at the sampled spatial scale of Boolathana (i.e. 2,400 m^2 for many condition x soil x stocking rate combinations). For example, the years of highest observed recruitment for *Eremophila maitlandii* and *E. forrestii* were 1984 - 1986. For the two bluebush (*Maireana platycarpa* and *M. polypterygia*) it was 1991 - 1993 and for *Ptilotus obovatus*, recruitment in 1993 was close to that of the other nine years combined. It was unreasonable to expect a model to predict this variation, given that we don't have a basic understanding of the spatial and temporal variability of recruitment and given that our observed values might not reflect wide area averages because of small plot sizes.

Four key conclusions were generated from the simulation exercise:

1) The constraint of a four-monthly time step seriously affects the accuracy of model outputs. In a sense, it was not possible to compare IMAGES (or its functional relationships) with other models while this constraint exists. Neither the expertise nor time was available within Agriculture WA to re-code and re-parameterise the model to a daily time step for the Aussie GRASS project.

2) Modelling all three components - shrub dynamics, shrub biomass and herbage biomass was difficult. The accuracy of the herbage modelling suffered because of the need to juggle the three components.

3) Unlike herbage biomass, neither shrub dynamics nor shrub biomass reset to zero at relatively regular intervals. Therefore, any errors in the modelling will compound over longer periods than for herbage biomass.

4) The model accuracy was very dependent on potential maximum shrub densities and potential maximum shrub and herbage biomass. At Boolathana, degradation of the Sable landsystem resulted in the removal of shrubs, but also caused an increase in herbage mass. The maximum density (or biomass) parameter estimates needed to be altered to reflect this. As an extreme example, the maximum density of *Maireana platycarpa* on the poor duplex soils had to be set to zero, otherwise, at low stocking, the model would attempt to increase the *M. platycarpa* density to that found on good duplex, whereas there are no *M. platycarpa* on the poor site. The required level of information (i.e. degradation mapping at 5 km x 5 km scale) will not be available to the Aussie GRASS project. Therefore it will not be possible to model shrub dynamics, biomass or herbage mass on such systems with any accuracy. This can largely be explained by state and transition models. The dynamics within states (on yearly timescales) can be modelled but the transition to other states and their subsequent modelling will prove very difficult for any generic model. This will also be true for other chenopod systems in Australia, e.g. the Hay Plain.

5.2.1.2.2 Modelling edible shrub biomass

Three factors are likely to prevent the inclusion of shrub biomass estimates in the Aussie GRASS spatial framework:

1) No model is currently available that can simulate browse biomass well, although it might be possible to parameterise herbage or grass models to simulate shrub biomass, say by having low decay rates (i.e. ‘long lived herbage’).

2) For most vegetation types the separation of browse into ‘eaten’ and ‘uneaten’ will be very difficult. This is partly due to individual species differences in palatability in different areas (e.g. *Eremophila forrestii* is very palatable on some parts of some landsystems and not at all palatable in other areas), and partly due to the fact that palatability is not absolute but depends on the other feed available.

3) Modelling shrub and herbage biomass in shrub-dominated systems will always depend on the state of the system. Observed biomass will be different on those sites in good condition compared to those sites in poor condition. To some extent the same is true in grassland systems, but in that case the variations in woody biomass due to condition are important in terms of competing for water and nutrients, but not in important in terms of providing edible biomass.

5.2.1.2.3 Recommendations

It may be naive to assume that we can model absolute biomass of shrub-dominated systems for the Aussie GRASS project. It is therefore recommended that resources be concentrated on parameterising the existing GRASP model as a best estimate of herbage biomass production in shrub dominated. Edible shrub biomass would not be modelled by GRASP. However, this may not matter since the vegetation mapping resolution will not allow us to map edible shrub density with any accuracy.

The use of model outputs would then be restricted to putting current growth (or TSDM) in historical context. Since many of the uses for Aussie GRASS products depend on seasonal context rather than absolute biomass this constraint is not overly restrictive.

5.2.1.3 Roshier data set

5.2.1.3.1 Method

Biomass at 11 sites located on downs country in the Broken Hill region was measured between March 1990 and March 1993. Sites were established in stony downs country and associated plains with bluebush and saltbush and measured biomass for fifteen categories of plants including *Astrebla* spp., *Stipa* spp., *Enneapogon* spp., *Danthonia* spp., other perennial grasses, annual herbs, annual chenopods and forbs. Daily rainfall was recorded at each site along with stocking rates at the time of measurement and interim periods.

Data from four of the Roshier paddocks (or sites) have been used to parameterise IMAGES. The data included sampling dates, biomass for individual species, and stocking rates. These data sets were used to provide the required model inputs of initial biomass (herbage and shrub) and average stocking rate for each paddock.

IMAGES also requires the input of maximum potential biomass and this was inferred from the data, as were other data inputs required by IMAGES such as initial shrub and herbage density and maximum potential density for each of these groups. Unfortunately, species for which density data were available did not (generally) correspond to species for which biomass data were available. Shrub densities and maximum potential densities were crudely inferred from the recorded data.

As a result of the above limitations, only one long lived, shrub group (*Maireana* genera) was able to be modelled. Palatability and susceptibility to grazing pressure for the group were ranked as intermediate and the group was modelled as drought tolerant.

Daily rainfall records were available for each of the paddocks although data for 1993 were not complete. Where rainfall data did not cover the entire period being simulated the data were supplemented with rainfall data from the nearest official rainfall gauging station.

5.2.1.4 Results and discussion

IMAGES did not model observed biomass very well. These results may be attributed to a number of factors including inadequate data, an example of which was the need to infer population densities of one species from information pertaining to a different species. The results may also reflect a difference in species composition between WA and NSW systems (e.g. the importance of perennial grasses in the NSW systems). The difference in rainfall regimes between WA and NSW may have also affected the model's performance, i.e. is the four-monthly time step used by IMAGES appropriate in the NSW system?

IMAGES was particularly inaccurate with predicting actual biomass during 1993. The use of supplementary rainfall data during this period may have contributed to the poor results.

Another concern with this exercise was that the Roshier data sets might not present an accurate reflection of shrub populations. For example, the Final Report clearly indicates that *Atriplex* spp. form an important component of the modelled systems, however no biomass data was collected for any *Atriplex* spp.

5.2.1.5 Discussion

The findings of Watson (1999) for Boolathana and the results reported here for Roshier highlight the problems associated with simulation of shrub density and biomass. Thus, as McKeon *et al.* (1996) showed that GRASP was able to simulate 62 – 72% of the variation in observed non-shrub biomass for the four Boolathana sites examined in their work, the recommendations of Watson (1999) have also been adopted for this report.

5.3 Western New South Wales

5.3.1 Introduction

This section reports on the results of the examination of the SEESAW[1] model in conjunction with GRASP using data sets for western NSW. All SEESAW simulations for this work were provided by CSIRO via a contract between DLWC and CSIRO (signed March 1998).

The evaluation of the SEESAW and GRASP models comprised the following steps:

1) comparison of models in terms of objectives, and physical and biological processes and a review of issues for parameterisation;
2) review of previous applications of GRASP to similar vegetation communities;
3) evaluation of existing parameter sets with the historical NSW pasture data sets collated in Aussie GRASS;
4) examples of calibrating GRASP to NSW data sets; and
5) comparison of simulation output from GRASP and SEESAW.

5.3.2 Comparison of models: objectives, physical and biological processes

The major objectives of using GRASP within the Aussie GRASS framework are:

1) to simulate pasture growth and biomass in 'near real time';
2) evaluate current conditions relative to historical conditions; and
3) forecast pasture production and assess the risk of degradation.

The major reason that GRASP was developed for tropical grasslands was the limited relationships between climatic variables (e.g. rainfall) and pasture growth. The above

[1] A separate document has been prepared by CSIRO (Marsden and Hodgkinson 1999) which details most of the data presented here for SEESAW.

objectives could not be met without construction of a model of soil water and plant growth. Of particular importance was the lack of grass growth when: 1) seasonal rainfall was low (< 200 mm); 2) temperature was too low; or 3) nutrient limitations occurred under high rainfall conditions.

The above objectives include the assessment of pasture growth and biomass in relative terms. The failure to simulate absolute TSDM values does not necessarily lead to inaccurate assessments in relative terms (e.g. percentiles of pasture growth, proportion of average pasture growth). Thus the comparison of SEESAW and GRASP has to consider implications for absolute and relative biomass attributes.

The major difference between SEESAW and GRASP is how each model represents the pasture and its composition. The composition of pastures varies depending on soils, landscape position, tree density, seasonal rainfall distribution and grazing history. The SEESAW model represents this botanical complexity by allowing the calculation of the simultaneous responses of five plant guilds to environmental/managerial conditions. Guilds exist for cool season ephemeral forbs, palatable cool season (C_3) perennial grasses, palatable warm season (C_4) perennial grasses, unpalatable warm season C_4 perennial grasses and shrubs. In contrast, the GRASP model is a sward model, in which a single set of 'lumped' parameters describes the aggregated functional characteristics of all the non-shrub components of the sward. In addition, SEESAW allows for landscape variability in terms of run-on and run-off zones, whilst GRASP does not. Thus the variation in species composition and landscape represent a major challenge for a 'sward/point' model.

To parameterise GRASP for the NSW rangelands the following issues were considered.

5.3.2.1 Run-off and run-on zones

GRASP simulates run-off from a 'typical' mid-slope landscape unit. Run-off can also be 'turned-off' representing situations with high infiltration rates. Run-on sites have been successfully simulated by adding run-off to rainfall to prepare a new 'rainfall' input file (as in Section 5.1.2.2.1). However, simultaneous simulation of run-off and run-on sites is not possible in GRASP. The choice of whether to simulate sites as run-off or run-on was a key component in parameterising sites, with soil type used as an indicator in the following studies.

5.3.2.2 Competition of trees and pasture

GRASP separately calculates transpiration (and nitrogen uptake) by trees and the herbaceous layer (grasses and forbs). Some validation of this approach has been provided by soil water measurements and the accurate representation of the average effects of variable tree density on grass growth. However, GRASP only accounts for a small proportion of seasonal variation in TSDM at high tree densities. The reasons are yet to be explained but are likely to include seasonal changes in species composition resulting in seasonal variation in parameters such as the critical nitrogen concentration of the sward at which growth stops, transpiration efficiency and detachment rates.

5.3.2.3 Representation of shrubs

The best approach to represent shrubs in GRASP is uncertain. Shrubs which have long-lived leaves and hence a near-permanent transpiration canopy, are best represented as 'trees' although no growth or senescence would be calculated. Shorter-lived shrubs could be represented using parameters associated with the 'stem' pool with slow rates of senescence and detachment. However, a limitation to this approach is that GRASP does not differentiate between the maximum cover of green leaf and green stem that can be supported by a given level of soil moisture and hence modification of GRASP code would be required to implement this approach.

5.3.2.4 Parameterisation of forbs and perennials

GRASP, through the simulation of leaf and stem pools in TSDM, provides the opportunity to represent some of the different senescence and detachment rates of forbs compared to perennial grass/shrubs. In GRASP the parameter that controls partitioning between leaf and stem, could be used to reflect different compositions of forbs and grasses for different sites. However, the parameter is not dynamic and hence cannot be used to represent within-year effects on plant guild composition. The point version of GRASP used in grazing management studies (McKeon *et al*. 2000) allows changes in key parameters to occur from year-to-year as a function of perennial/annual composition (Ash *et al*. 1966, McKeon *et al*. 2000). Whilst this procedure could be adapted to western NSW it is not currently available in the Aussie GRASS version of GRASP.

As stated above, the parameter controlling partitioning between leaf and stem could be used to represent the faster detachment rate of forbs compared to other plants guilds but the existing code in GRASP has some limitations. Different sensitivities of plant guilds to frost and water stress cannot be represented. Similarly, major growth parameters that vary between species (temperature effects on growth and critical nitrogen concentration) are lumped.

5.3.2.5 Soil moisture restriction on plant growth

The soil moisture threshold at which above-ground growth stops is a key parameter for the accurate simulation of plant growth under low rainfall. However, it is not clear how best to represent the differences between plant guilds. Ephemerals appear to stop growth at the same time as soil moisture extraction (in 0 - 50 cm zone) stops. In contrast, above-ground growth in perennial C_4 grasses has been observed to stop whilst moisture extraction has continued to occur. However, as we have no measurements of moisture extraction on the same soil for swards of different pasture composition it is not clear whether the above observation is better represented by changing the plant available water range as a function of plant guild or alternatively, changing the threshold for stopping above-ground growth. The latter approach has been adopted in studies with GRASP (McKeon *et al*. 2000) where annual changes in composition have been modelled. However, GRASP is unable to represent within-year changes in parameters that would result from seasonal changes in the composition of plant species.

5.3.2.6 Nitrogen availability

Nitrogen availability is reset at the start of the growing season (late spring in tropical grasslands) and nitrogen uptake occurs as a function of transpiration until potential annual nitrogen uptake has been reached. This simplistic approach reasonably simulates nitrogen yield where there is a reliable growing season and has been applied to both summer and winter rainfall zones. However, where rainfall can occur at any time of year (aseasonal) such an approach may be inappropriate. For example, in the simulation of ephemerals in central Australia (Section 5.1.2), GRASP was changed to allow potential nitrogen uptake to be reset for each growth pulse (2 to 3 pulses per year) after the soil had dried out and presumably organic material was pre-conditioned for rapid mineralisation during the next rainfall/growth pulse (G. Baldock pers. comm.). This algorithm is currently not available in the Aussie GRASS version of the model.

Whilst it could be argued that an annual reset is appropriate for western NSW given the presence of some perennial grasses and shrubs, the most appropriate date for annual resetting of nitrogen availability is unclear. If winter growth of forbs reduces nitrogen availability for subsequent summer growth then an end-of-summer reset would be most appropriate. Alternatively if good summer growth reduces subsequent winter growth because of lack of nitrogen, then a late spring reset would be more appropriate. Examples of the latter case may have occurred at Ivandale in 1973/74 and at Runnymede and Tundulya in 1983/84 – three of the western NSW data sets used later in this section. Good rainfall in summer 1973/74 resulted in high annual grass growth but subsequent winter/spring rainfall did not produce high forb growth as might have been expected. At both Tundulya and Runnymede the high growth of forbs in spring 1983 did not appear to affect subsequent grass growth. Thus a spring reset would appear to be most appropriate. However in analysis of NDVI time series from 1982 to 1993, J.O. Carter (pers. comm.) found that the 1st January was the time of lowest NDVI reflecting the low moisture condition during summer during this decade (1982-1993). Thus an early summer date could be used to reset nitrogen availability.

These issues and actions regarding parameterisation are documented in Section 5.3.4.1.

5.3.3 Review of previous studies using GRASP in semi-arid woodlands

Several parameter sets have been previously developed for GRASP that have application to NSW rangelands.

5.3.3.1 Mulga grasslands

Johnston (1996) developed a parameter set for mulga grasslands (C_3 perennial grasses and forbs) based on several field studies centred on Charleville, south-west Queensland. Plant growth parameters were derived from intensive field work (3-weekly harvests) using the GUNSYNpD method (McKeon *et al*. 1990, Day *et al*. 1997), which was designed to measure or easily derive as many of the key parameters (e.g. peak N yield) as possible, and reduce the number of parameters that have to be calibrated (e.g. potential regrowth rate, transpiration efficiency). Comparison with a previous growth study (Christie 1978) provided independent validation of plant growth, soil moisture and nitrogen uptake. Data collected in a major grazing trial (Arabella near Charleville, Orr *et* *al*. 1993) provided some further validation of major growth episodes and allowed derivation of: 1) detachment rates under grazing; and 2) a model of grass basal area. However, it was not clear whether the effects of variable tree (mulga) density were correctly modelled at Arabella because of uncertainty regarding estimates of tree density in the large grazed paddocks.

The mulga parameter set and model were evaluated for variable tree densities using the 'Boatman' mulga thinning trial of Beale (1971). Whilst the average effect (over 10 years) of increasing tree density was accurately simulated, reflecting the dominating process of competition for moisture, little of the year-to-year variation was explained. Inspection of data on botanical composition indicated that the irregular appearance of C_4 grasses (e.g. *Aristida* spp.) was a major source of errors (K.A. Day pers. comm.). Models of composition change are yet to be coded as these known deficiencies have limited impact on current model applications (e.g. drought analysis, long-term carrying capacity assessment). Thus the mulga grassland parameter set has been derived and evaluated against at a range of sites (Charleville, Arabella, Boatman) in the south-west Queensland mulga lands.

The mulga grassland parameter set had also been evaluated in terms of explaining the spatial variation in historical stock numbers. Using the mulga parameter set, average pasture growth was calculated for each NSW Pasture Protection District in the rangeland region and for different time periods (J. Yee Yet unpublished data). Average pasture growth was compared with reported stock numbers with cattle and horses converted to sheep equivalents (Beadle 1948). For the periods 1904 to 1943 and 1904 to 1957 there were strong correlations between simulated growth and average stock numbers suggesting that, at this spatial scale, the parameter set and simulated growth provide reasonable relative assessment. The strongest correlation was for the period 1904 to 1957 which included major perturbations in terms of increases in woody weeds (Anon 1969), decline in rabbits after release of myxomatosis (Condon 1986), and the extreme drought of 1944-45 (Beadle 1948).

5.3.3.2 Open shrublands

Robertson (1987) measured TSDM and species composition every three months at 213 sites at Kinchega National Park (near Menindee, NSW) and 100 sites on a neighbouring grazing property (Tandou) from August 1980 to February 1984. The vegetation included mainly annual forbs, although annual grasses, perennial forbs, grasses and 'sub-shrubs' contributed to one growth pulse. The observation sites covered a range of soils but Robertson (1987) stated that 'there was no overall difference in pasture biomass between heavy textured and light textured soils'. GRASP was parameterised using all the TSDM data with soil moisture parameters estimated from Wellard (1987). Independent validation was evaluated using rangeland assessment program (RAP) data collected subsequently at the same site (D. Hart and R. Richards unpublished data). The parameter set was also tested by K.A. Day (pers. comm.) with the data of Zallar (1986) collected in north-western Victoria. The successful validation of the parameter set suggests it may be applicable to some of the other NSW sites. However, a limitation of the parameter set is that it does not include the effects of grazing history nor has it been tested over a range of shrub/tree densities.

The analysis of Kinchega data suggested different detachment rates depending on the species type (annuals 0.006 kg/kg/day, perennials 0.003 kg/kg/day) contributing to growth pulses. For the parameter set an average detachment rate (0.0045 kg/kg/day) was used.

5.3.3.3 Summary

The ‘mulga’ and ‘Kinchega’ parameter sets previously developed with GRASP represent different vegetation types and have contrasting representations of the effects of trees and grazing history. The mulga grassland parameter set includes a dynamic model of perennial grass basal area that responds to climatic variability, grazing and tree density. However, the potential growth of forb and ephemeral vegetation component can be independent of grazing history and tree density and hence the mulga grassland parameter set can underestimate this component in pasture.

The Kinchega parameter set was based mainly on forbs and annual species and has a constant potential growth rate (i.e. essentially a constant seed bank). As yet we do not have sufficient information to vary this parameter with soils, climate, grazing history and tree/shrub density.

5.3.4 Materials and methods

Eight data sets were jointly supplied by CSIRO and NSW Agriculture for use in the analysis and were detailed in earlier documents (Marsden 1998, Bean and Clipperton 1999):

- Lake Mere;
- Runnymede;
- Tundulya;
- Lynwood;
- Ivandale;
- Double Dams;
- East Wygilla; and
- Fowlers Gap.

These data sets were used to gain simulation output from the GRASP and SEESAW models. GRASP simulations were undertaken by Greg McKeon of the Queensland Department of Natural Resources and Mines (NR&M) and SEESAW simulations by Steve Marsden of CSIRO.

The Lake Mere data set was used in the development of the SEESAW model and hence is not an independent validation. SEESAW was run for the other seven locations with only changes to the initial basal area and seed banks for the various guilds (Table 10). These variables determine where the location lies in terms of the perennial – annual pasture community continuum. Initial basal area was set based on the observed peak biomass levels where each percentage point of basal area value was equivalent to approximately 250 kg DM/ha. The initial basal area values were used to generate new perennial plant biomass after the first effective rainfall as well as limiting maximum biomass production. Thereafter basal area was dynamic and fluctuated with seasonal conditions. Seed bank levels (kg/ha) for the annual guilds were set based on observed yields of the guilds at each of the locations. The seed bank was used for initiating biomass (germination) after effective rainfall. These values represented the maximum biomass that can be used, however, with sub-optimal temperature and/or soil water the biomass values at germination may be lower. The SEESAW model runs were begun nine months before the first observation date to as to allow an 'equilibrium' to be achieved. As the model runs began in mid-summer, initial annual plant biomass values were assumed to be zero.

SEESAW is also able to account for the process of run-on although this feature was not utilised here as there was inadequate descriptive and climatic (rainfall intensity) data available for most of the sites.

Table 10. Initial basal area and seed banks used to initialise the SEESAW model for the eight data sets.

Location	Seed biomass (kg/ha)				Basal area (%)			
	Annual forb	Perennial forb	Annual grass	Chenopod	Perennial chenopod	C3 grass	Palatable C4 grass	Unpalatable C4 grass
Lake Mere	30					1.5	0.25	0.5
Runnymede	30		5			1.5	1.5	
Tundulya	30					1.5		
Lynwood	15	15				0.1		1.0
Double Dams	30		5	5				
East Wygilla	30		5	5				
Fowlers Gap	15		15		1.5			
Ivandale	5		30		1.5			

The GRASP model was initially run for all eight locations using the perennial mulga grassland parameter set described in Section 5.3.3.1 (No. 1 run), and the Kinchega parameter set described in Section 5.3.3.2 (No. 2 run). The simulations were conducted with: 1) tree basal area (TBA) set at 0.5 m^2/ha for mulga and 3.0 m^2/ha for Kinchega; and 2) TBA estimated for each of the sites from the Aussie GRASS data layers (Table 11). Whist the results from using the mulga and Kinchega parameter sets were encouraging (detailed below in Section 5.3.5), new parameter sets calibrated to each of the sites were also developed. This parameter development process is outlined in the following section.

5.3.4.1 Calibration of GRASP for NSW rangeland sites

As the NSW data sets included only a few major growth pulses and there was a great danger of calibrating too many parameters, the approach adopted for this report was to firstly estimate as many parameters as possible from other information sources, and then, secondly, calibrate only one parameter, 'potential regrowth rate'. This parameter was likely to integrate some of the effects of tree density, pasture basal area, seed banks, grazing history, species composition and soil fertility. The mulga grassland parameter set was used as the base parameter set as many of the parameters were derived from detailed measurements in field studies in south-west Queensland.

5.3.4.1.1 Soil water parameters

Site parameters such as available soil water and vegetation composition were those used in SEESAW (Tables 11 and 12). Run-off was considered to occur on the red earth sites but not on the sandy, dune or swale sites. The effectiveness of tree litter as cover in run-off calculations was linked to grazing, i.e. on grazed sites tree litter was not considered effective in reducing run-off.

5.3.4.1.2 Tree basal area

Local estimates of TBA derived from remote sensing were used except for Runnymede and Tundulya. Marsden and Hodgkinson (1998) noted that at these ungrazed site shrub/tree cover had little effect on pasture growth. As discussed above, GRASP only includes the competitive effects of woody cover and inclusion of estimates of TBA resulted in simulations of low grass basal area and yield (Table 21). The lack of yield reduction in observed data for ungrazed sites could be due to several causes:

1) modification of pasture microclimate;
2) fertility addition due to tree litter; and
3) lack of competition for moisture with shrubs/trees accessing lower surface layers.

Effects 1) and 2) would be partially included in the parameterisation of 'potential regrowth rate'. However, to reduce competition for moisture at these sites TBA was halved - effectively reducing moisture extraction by trees from the top 1 metre.

5.3.4.1.3 Detachment rates

As discussed above, a feature of the sites was the large variation in botanical composition both between sites and over time resulting in substantial differences in detachment rate. As a result we used the 'leaf' and 'stem' pools in GRASP to represent 'fast' and 'slow' detaching material. The 'fast' detachment rate was set at 0.02 kg/kg/day (i.e. 15% per week), a value suitable for annual forbs (Marsden and Hodgkinson 1998). The 'slow' detachment rate was set at 0.0025 kg/kg/day representing the average of detachment rates derived from several typical perennial grass pastures.

5.3.4.1.4 Partitioning growth between plant types

For each site the parameter which partitions growth between 'fast' and 'slow' pools (p123) was derived from the botanical composition estimates used to initialise SEESAW for seed banks and perennial basal area (Table 12):

p123 = annual_forb_seed_bank / (annual_forb_seed_bank + a_1 * perennial_basal_area)

where the value of co-efficient a_1 (13.3) was derived from Lake Mere initial values to give a value for parameter p123 of 0.5. Values of p123 ranged from 1.0 for sites with only annual forbs (e.g. Double Dams) to 0.20 for Ivandale that had a high perennial plant component.

Table 11. Site attributes used in GRASP simulations for eight sites in the NSW Rangelands. Local tree basal area (TBA) was derived from Aussie GRASS; shrub and tree density estimates were provided by S. Marsden; TBA used in GRASP (p291) was reduced for high TBA ungrazed sites to account for reduced competition; soil attributes were from S. Marsden as used in SEESAW; run-off parameters were linked to soil type, i.e. red earths; tree litter was considered as effective cover in run-off calculation where there was no grazing.

Site	Trees				Soil Attributes					Run-off (p270)	Effective tree litter (p047)
	Local TBA (m^2/ha)	Shrub density	Tree density	TBA used (m^2/ha, p291)	Type	Available Soil Moisture (mm)					
						0-10 cm	10-50 cm	50-100 cm	Total 0-100 cm		
Lake Mere	1.22	Low	Very low	1.22	Hard red earth	12	41	36	89	Yes	No
Runnymede	6.33	High	Low	3.16	Hard red earth	12	41	45	98	Yes	Yes
Tundulya	4.78	Moderate	Very low	2.40	Soft red earth	11	36	39	86	Yes	Yes
Lynwood	6.22	Moderate	Low	6.22	Deep red sands	12	42	50	104	No	No
Double Dams	0.88	na	na	0.88	Swale	12	49	55	116	No	No
East Wygilla	0.44	na	na	0.44	Swale	12	49	55	116	No	No
Fowlers Gap	0.11	na	na	0.11	Dune	11	34	45	90	No	No
Ivandale	1.00	Moderate	Very low	1.00	Calcareous red earth	14	43	45	102	Yes	Yes

na – not available

Table 12. Selected trial data, GRASP inputs, GRASP parameters and GRASP outputs. Seedbank for annual forb and perennial basal area were from SEESAW inputs and used to calculate partitioning of growth between fast and slow detaching pools (p123). Grazing and perennial C_4 basal area data were from trial observations and SEESAW inputs, and have been used to estimate the nitrogen concentration of the sward at which growth stops (critical %N - 0.68 for C_4, 0.88 for C_3) and soil moisture index at which growth stops (p149). Calibrated potential regrowth was derived from the first two growth observations. '% forbs' is the percentage of forbs recorded in the in the two observations used in calibration of GRASP. For the grazing attributes, utilisation was calculated as intake/growth, and grazing pressure as annual intake/average pasture yield. Intake was calculated from stocking rate and assumed a 50 kg sheep eats 1.3 kg DM per day.

	Vegetation					GRASP parameters			Grazing attributes averaged for observation period					
Site	**Annual forb seed (kg/ha)**	**Perennial basal area (%)**	**Partitioning growth (p123)**	**Grazing**	**Perennial C_4 basal area (%)**	**Critical % N (p101)**	**Soil moisture index (p149)**	**Calibrated potential regrowth (p006)**	**% forbs**	**Stocking rate (sheep /ha)**	**Simulated growth (kg DM/ha/day)**	**Utilisation (%)**	**Average standing biomass (kg DM/ha)**	**Grazing pressure (%)**
Lake Mere	30	2.25	0.50	Yes	0.75	C_3	0.4	6.5	0.56	0.30	1.70	23	399	36
Runnymede	30	3.0	0.43	No	1.5	C_4	0.3	11.0	0.32	0.00	4.24	0	1553	0
Tundulya	30	1.5	0.60	No		C_3	0.4	20.0	0.27	0.00	2.14	0	766	0
Lynwood	15	1.1	0.50	Yes	1.0	C_4	0.3	2.5	0.56	0.30	1.02	38	310	46
Double Dams	30	0.0	1.00	Yes		C_3	0.4	25.0	0.96	0.27	1.86	17	207	62
East Wygilla	30	0.0	1.00	Yes		C_3	0.4	4.5	0.96	0.19	1.13	22	137	66
Fowlers Gap	15	1.5	0.43	Yes		C_3	0.4	17.5	0.26	0.44	2.01	28	872	24
Ivandale	5	1.5	0.20	No		C_3	0.4	11.5	0.09	0.00	3.70	0	648	0

5.3.4.1.5 Other GRASP parameters

For the two sites with significant C_4 grass content (Runnymede and Lynwood), the parameters describing the nitrogen concentration of the sward at which growth stops ('critical % N', p101) and the soil water index at which growth stops ('threshold soil water index above-ground growth', p149) were set to typical perennial grass C_4 values (Table 12). For other sites C_3 values were used.

5.3.4.1.6 Initial conditions

The initial biomass and grass basal area values were:

- green and dead biomass pools set to values taken from the SEESAW simulation; and
- grass basal area (or plant density) set to 1.0%.

5.3.4.1.7 Calibration of potential regrowth rate

Values for potential regrowth rate were calibrated to match the first two observations associated with growth pulses, a similar procedure used previously in calibrating GRASP with $GUNSYN_pD$ data (Day *et al.* 1997). For five sites (Lake Mere, Lynwood, Double Dams, East Wygilla, Fowlers Gap) the observations were associated with the same growth pulse whilst for the other three sites two growth pulses were involved. There was a tenfold variation in calibrated potential regrowth rate: 2.5 to 25.0 kg DM/ha/day (Table 12). There was no consistent pattern in terms of the effects of tree density, grazing or botanical composition on potential regrowth rate. Other possible influences such as previous grazing history, accuracy of rainfall during initial growth pulses and initial condition inputs were not able to be evaluated with the information available. Semi-independent validation was evaluated with remaining observations in the time series as detailed in the following section.

5.3.5 Simulation results

5.3.5.1 Lake Mere

The SEESAW model was able to explain 79% (P<0.001) of the variation in total biomass at the Lake Mere site (Table 13, Figure 14). The best GRASP model simulation (No. 1 run with TBA = 1.22 m^2/ha), accounted for 88% (P<0.001) of the variation in total biomass. Full results are shown in Table 13.

Table 13. Simulation results for the Lake Mere site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.79***
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.87***
GRASP No. 1 simulation (mulga parameter set) and TBA = 1.22 m^2/ha	0.88***
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.12ns
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 1.22 m^2/ha	0.24**
GRASP – potential regrowth rate calibrated for the site	0.85***
GRASP – using average potential regrowth rate for all the sites	0.83***

* P<0.05, ** P<0.01, *** P<0.001, ns not significant – P>0.05

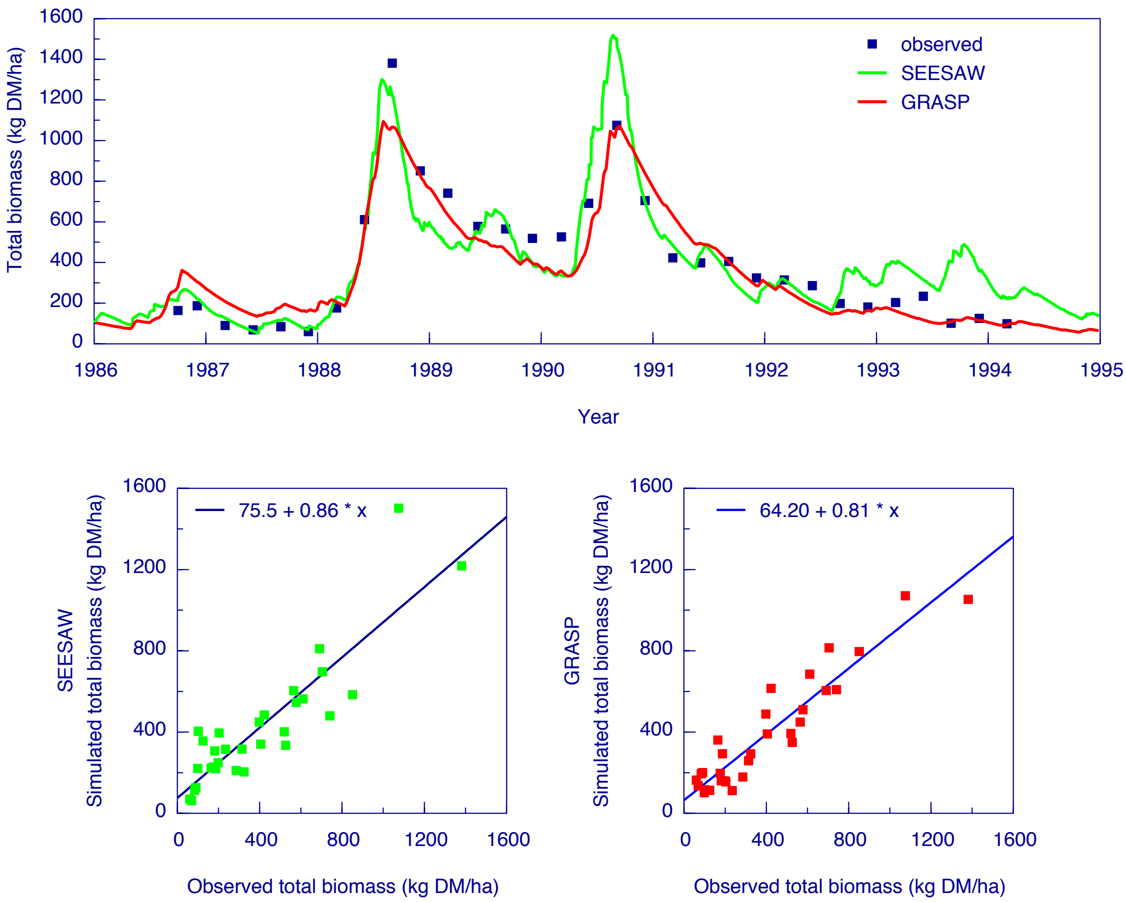

Figure 14. Observed and simulated total biomass for Lake Mere. The GRASP output was from the No. 2 rum with TBA = 1.22 m^2/ha.

5.3.5.2 Runnymede

The SEESAW model was able to explain 14% (P>0.05) of the variation in total biomass at the Runnymede location (Table 14 and Figure 15).

The best GRASP model simulation (using the average calibrated potential regrowth rate) accounted for 70% (P<0.01) of the variation in total biomass. Full results are shown in Table 14.

Table 14. Simulation results for the Runnymede site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.14 ^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.29 ^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 3.16 m^2/ha	0.51*
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.28 ^{ns}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.16 m^2/ha	0.17 ^{ns}
GRASP – potential regrowth rate calibrated for the site	0.69**
GRASP – using average potential regrowth rate for all the sites	0.70**

P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

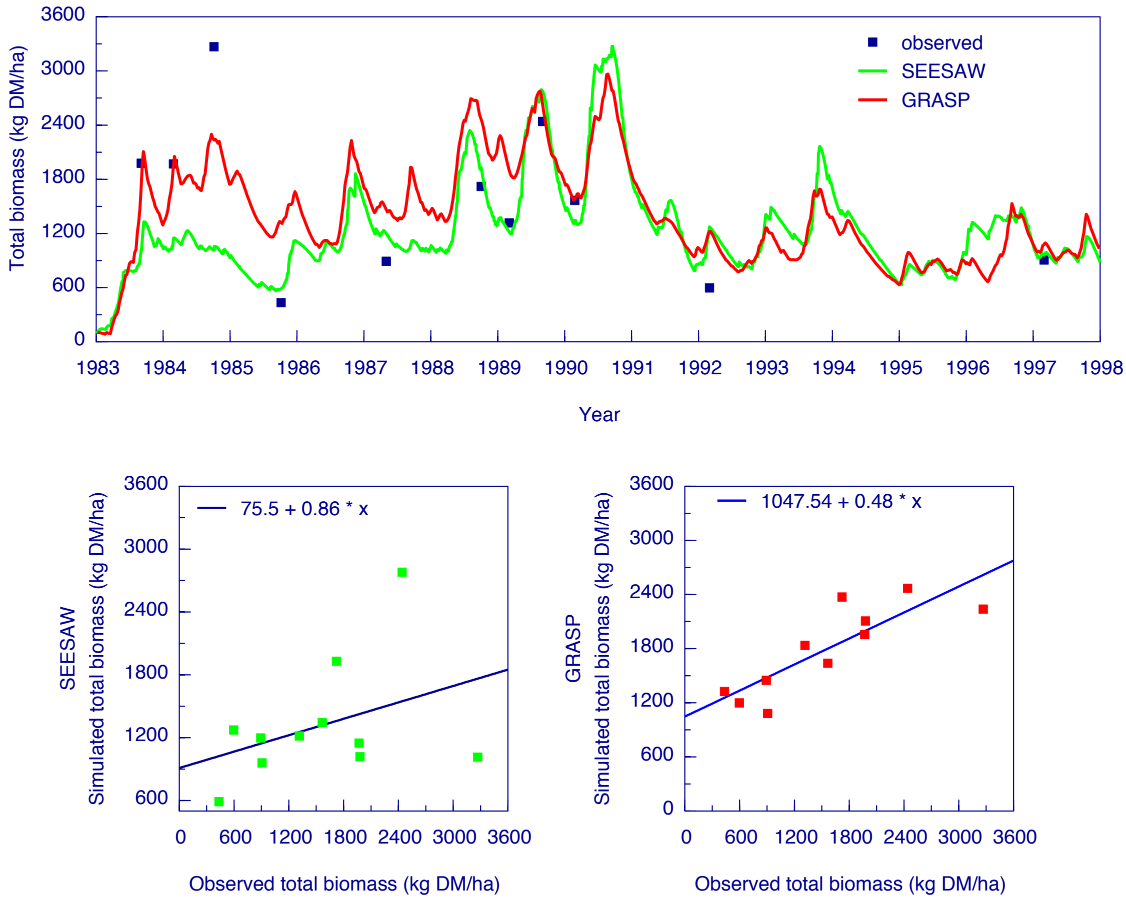

Figure 15. Observed and simulated total biomass for Runnymede. The GRASP output was produced using the average calibrated potential regrowth rate.

5.3.5.3 Tundulya

The SEESAW model was able to explain 37% (P<0.05) of the variation in total biomass at the Tundulya location (Table 15 and Figure 16). The best GRASP model simulation (using the average calibrated potential regrowth rate) accounted for 24% (P>0.05) of the variation in total biomass. Full results are shown in Table 15.

Table 15. Simulation results for the Tundulya site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.37*
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.18 ns
GRASP No. 1 simulation (mulga parameter set) and TBA = 2.40 m^2/ha	0.14 ns
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.20 ns
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 2.40 m^2/ha	0.20 ns
GRASP – potential regrowth rate calibrated for the site	0.24 ns
GRASP – using average potential regrowth rate for all the sites	0.24 ns

* P<0.05, ** P<0.01, *** P<0.001, ns not significant – P>0.05

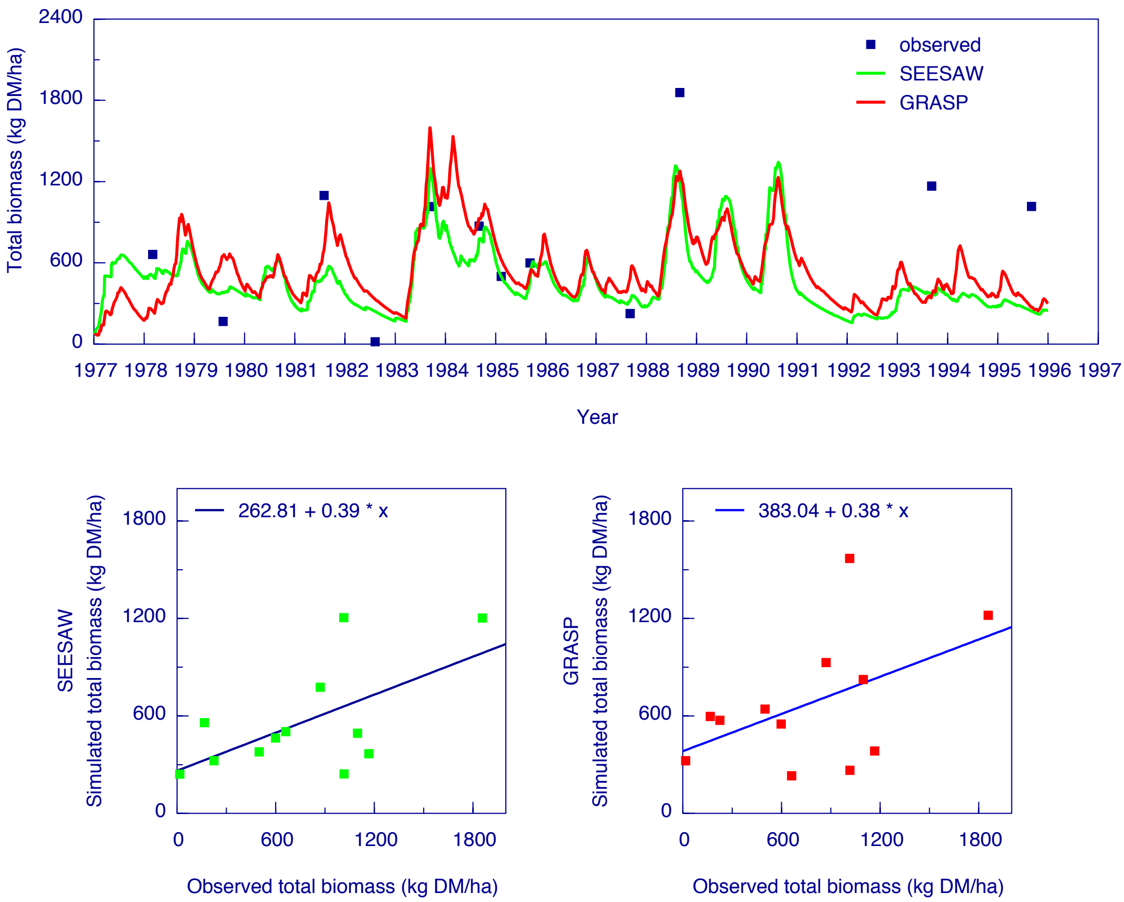

Figure 16. Observed and simulated total biomass for Tundulya. The GRASP output was produced using the average calibrated potential regrowth rate.

5.3.5.4 Lynwood

The SEESAW model was able to explain 91% P<0.001) of the variation in total biomass at the Lynwood location (Table 16 and Figure 17). The best GRASP model simulation (using the average calibrated potential regrowth rate) accounted for 87% (P<0.001) of the variation in total biomass. Full results are shown in Table 16.

Table 16. Simulation results for the Lynwood site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.91^{***}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.79^{***}
GRASP No. 1 simulation (mulga parameter set) and TBA = 6.22 m^2/ha	0.77^{***}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.59^{**}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 6.22 m^2/ha	0.73^{***}
GRASP – potential regrowth rate calibrated for the site	0.75^{***}
GRASP – using average potential regrowth rate for all the sites	0.87^{***}

* P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

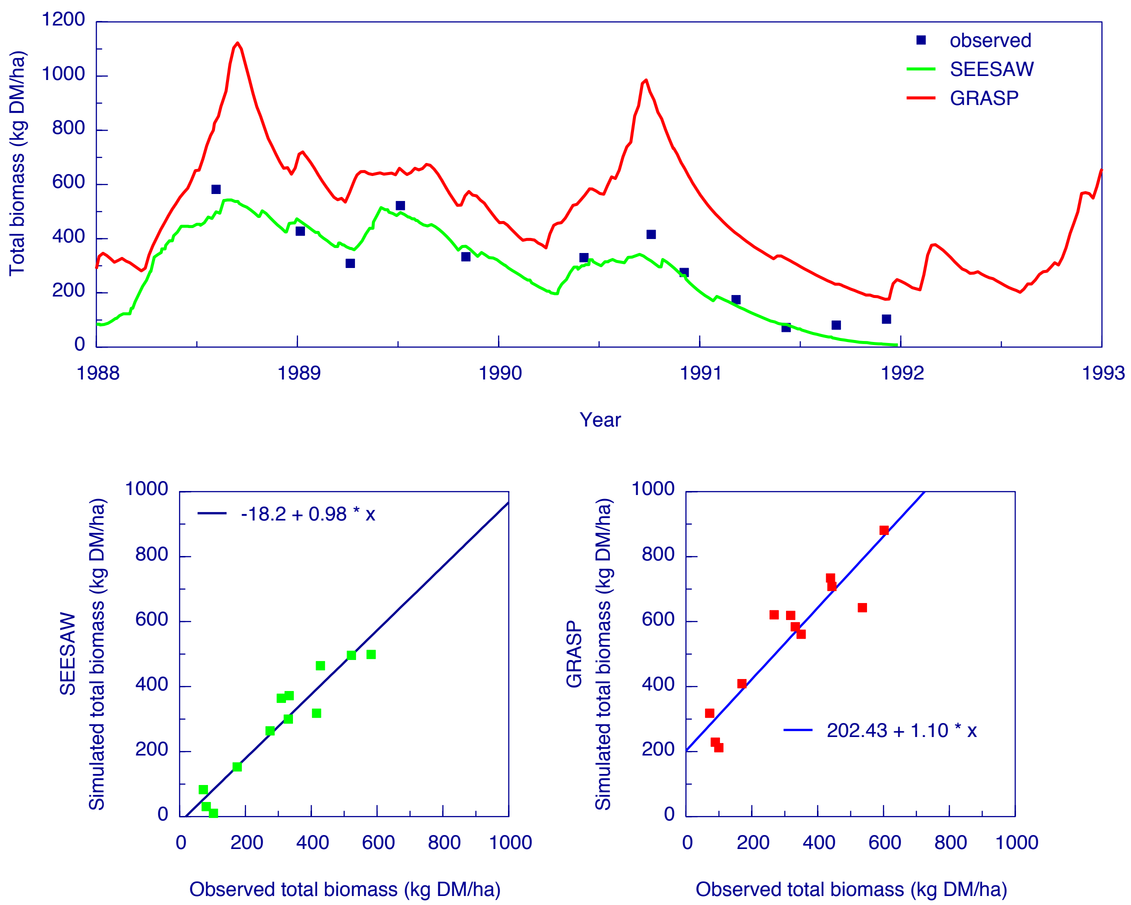

Figure 17. Observed and simulated total biomass for Lynwood. The GRASP output was produced using the average calibrated potential regrowth rate.

5.3.5.5 Double Dams

The SEESAW model was able to explain 73% (P<0.001) of the variation in total biomass at the Double Dams location (Table 17 and Figure 18). The best GRASP model simulation (using the site calibrated potential regrowth rate) accounted for 87% (P<0.001) of the variation in total biomass. Full results are shown in Table 17. It should be noted that both sets of output rely on a single data point for their good correlation values.

Table 17. Simulation results for the Double Dams site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.73^{***}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.26^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.88 m^2/ha	0.29^{ns}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.42^{*}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 0.88 m^2/ha	0.28^{ns}
GRASP – potential regrowth rate calibrated for the site	0.87^{***}
GRASP – using average potential regrowth rate for all the sites	0.85^{***}

* P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

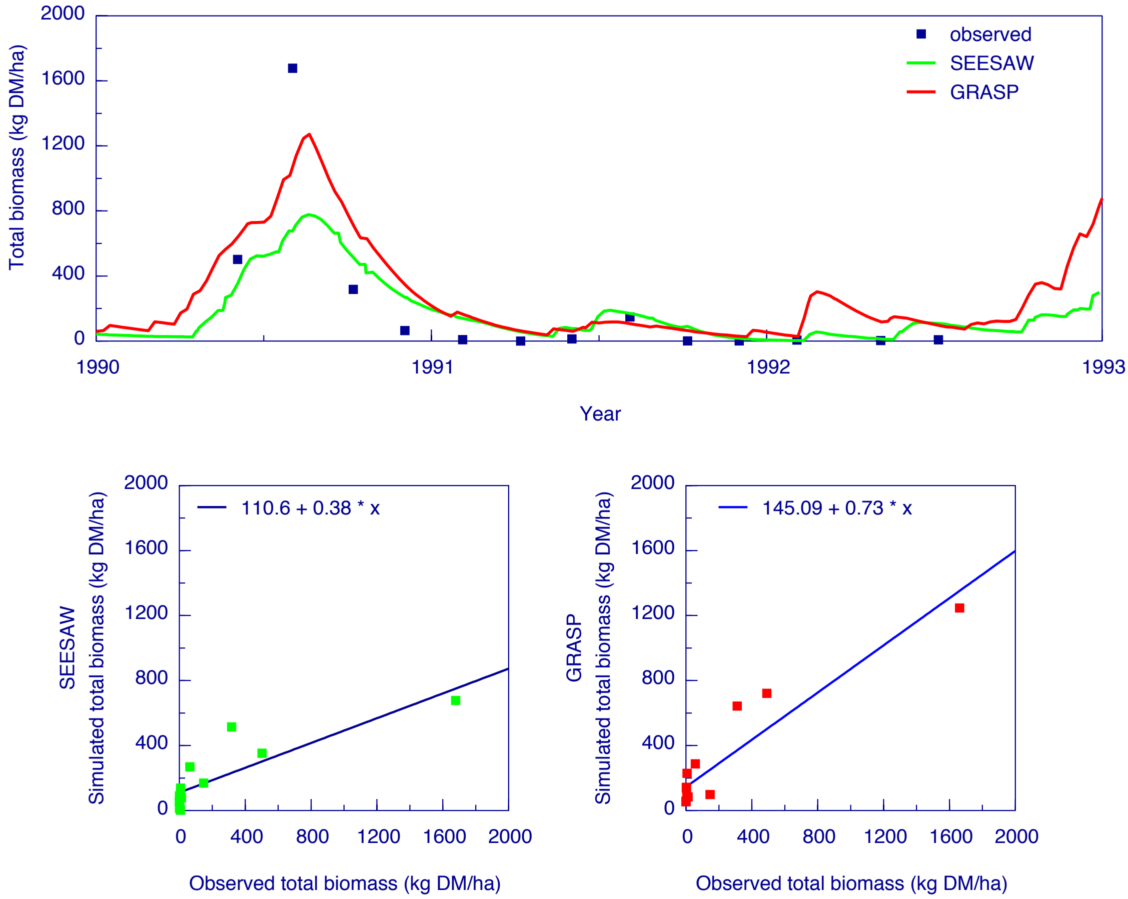

Figure 18. Observed and simulated total biomass for Double Dams. The GRASP output was produced using the site calibrated potential regrowth rate.

5.3.5.6 East Wygilla

The SEESAW model was able to explain 89% (P<0.001) of the variation in total biomass (including chenopod biomass) at the East Wygilla location (Table 18 and Figure 19). The best GRASP model simulation (using the average site calibrated potential regrowth rate) accounted for 98% (P<0.001) of the variation in total biomass (excluding chenopod biomass. Full results are shown in Table 18.

Table 18. Simulation results for the East Wygilla site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.89^{***}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.25^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.44 m^2/ha	0.24^{ns}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.46^{*}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 0.44 m^2/ha	0.23^{ns}
GRASP – potential regrowth rate calibrated for the site	0.75^{***}
GRASP – using average potential regrowth rate for all the sites	0.94^{***}

* P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

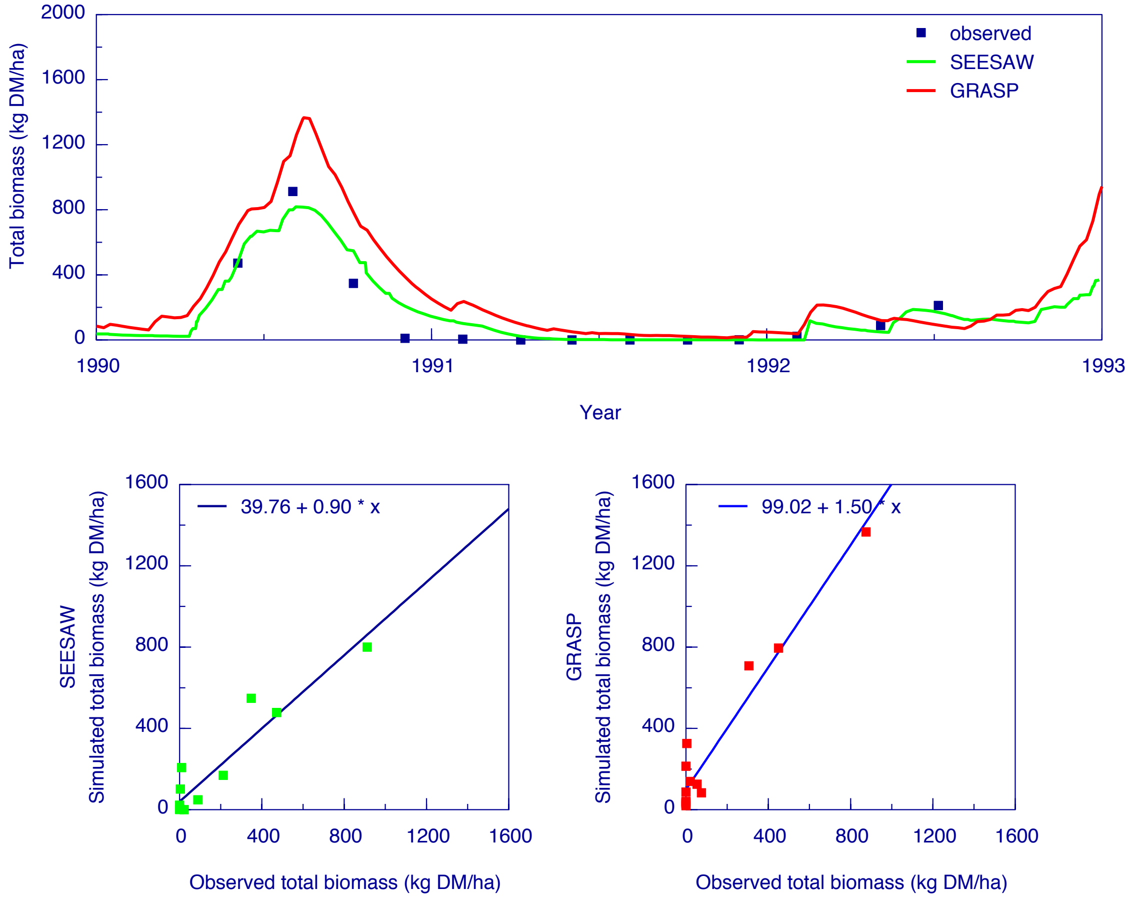

Figure 19. Observed and simulated total biomass for East Wygilla. The GRASP output was produced using the average calibrated potential regrowth rate.

5.3.5.7 Fowlers Gap

The SEESAW model was able to explain 91% (P<.0.05) of the variation in total biomass at the Fowlers Gap location (Table 19 and Figure 20). The best GRASP model simulation (using the average site calibrated potential regrowth rate) accounted for 98% (P<0.001) of the variation in total biomass. Full results are shown in Table 19.

Table 19. Simulation results for the Fowlers Gap site.

Model and simulation	TSDM correlation (r^2)
SEESAW	0.91^{*}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.91^{*}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.11 m^2/ha	0.91^{*}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.94^{**}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 0.11 m^2/ha	0.83^{*}
GRASP – potential regrowth rate calibrated for the site	0.98^{***}
GRASP – using average potential regrowth rate for all the sites	0.98^{**}

* P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

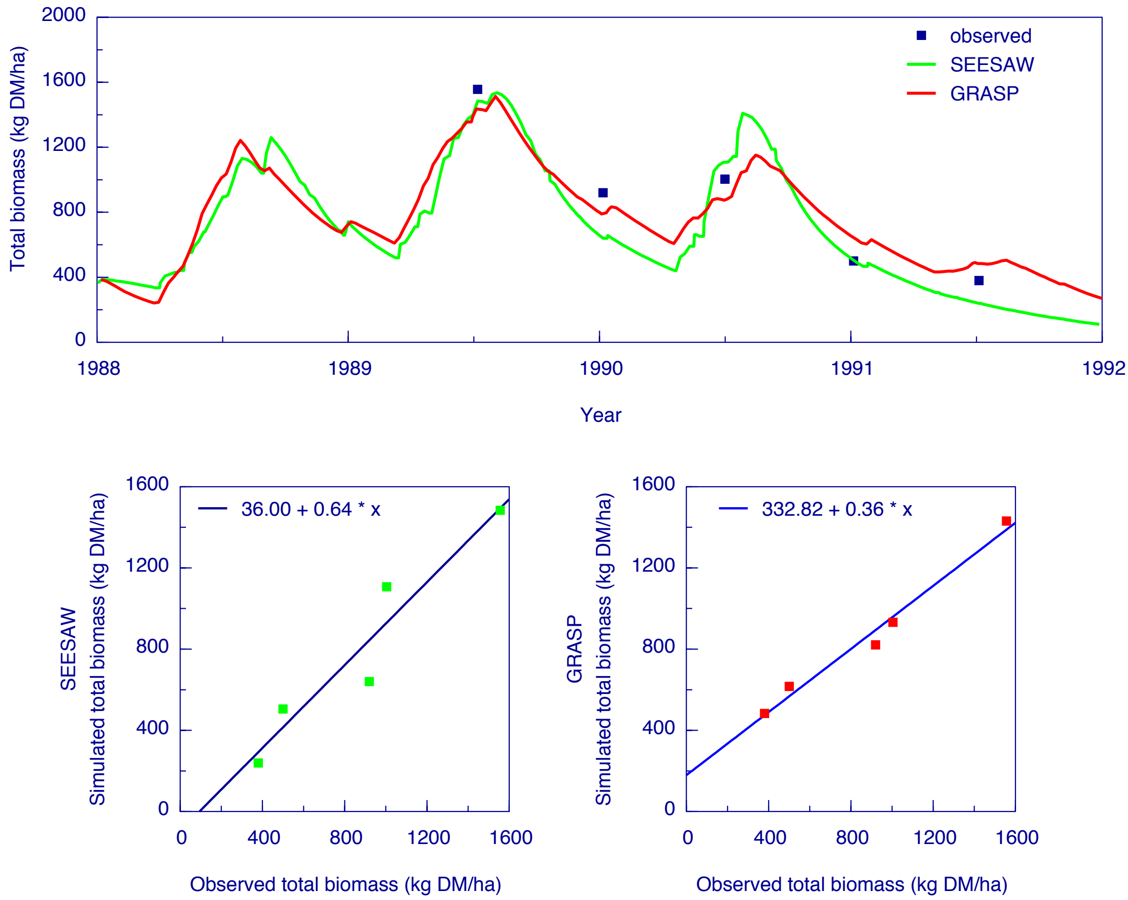

Figure 20. Observed and simulated total biomass for Fowlers Gap. The GRASP output was produced using the average calibrated potential regrowth rate.

5.3.5.8 Ivandale

The SEESAW model was able to explain 25% (P>0.05) of the variation in the total biomass pool at the Ivandale site (Table 20 and Figure 21). The best GRASP model simulation (No. 2 run with TBA = 3 m^2/ha) accounted for 40% (P<0.05) of the variation in total biomass. Full results are shown in Table 20.

Table 20. Simulation results for the Ivandale site.

Model and simulation	**TSDM correlation (r^2)**
SEESAW	0.25^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 0.5 m^2/ha	0.15^{ns}
GRASP No. 1 simulation (mulga parameter set) and TBA = 1.0 m^2/ha	0.15^{ns}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 3.0 m^2/ha	0.40^{*}
GRASP No. 2 simulation (Kinchega parameter set) and TBA = 1.0 m^2/ha	0.38^{*}
GRASP – potential regrowth rate calibrated for the site	0.13^{ns}
GRASP – using average potential regrowth rate for all the sites	0.12^{ns}

* P<0.05, ** P<0.01, *** P<0.001, ^{ns} not significant – P>0.05

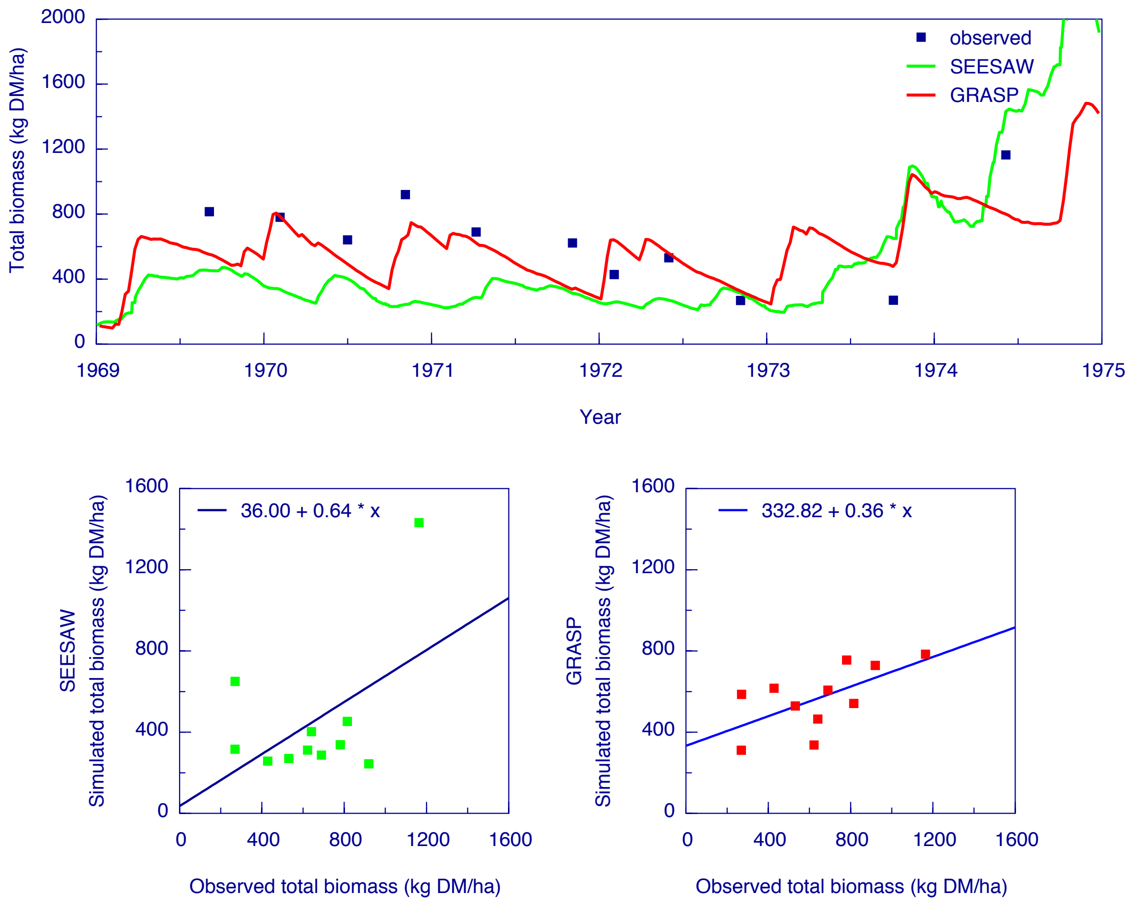

Figure 21. Observed and simulated total biomass for Ivandale. The GRASP output was produced using the No. 2 run with TBA = 3 m^2/ha.

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5.3.6 Discussion

The results from the SEESAW and GRASP simulations have been summarised in Table 21.

5.3.6.1 GRASP parameter sets

For Lake Mere, the GRASP mulga parameter set provided simulations in reasonable agreement with observed data. Inclusion of estimated TBA improved agreement (r^2 = 0.88, n = 31, RMS 114 kg DM/ha, mean simulated TSDM 388 compared to observed mean TSDM 399 kg DM/ha). Similar agreement occurred at Fowlers Gap although the number of observations was small (n = 5). However, for the other six sites there was little agreement. Inclusion of estimated actual TBA improved agreement in terms of mean TSDM for six of the eight sites but at Runnymede and Tundulya the inclusion of the high density of shrub/tree cover led to simulated yields well below those observed. and Marsden and Hodgkinson (1998) noted that at these ungrazed sites, in contrast to grazed sites, there was little apparent effect of high shrub/tree cover on pasture yield.

Compared to the mulga parameter set, simulations with the Kinchega parameter set were in closer agreement to the overall mean of the 106 observations and had higher correlations for four sites. However, agreement was generally poor and inclusion of estimated actual TBA did not substantially increase agreement except in the case of Lynwood which was grazed and had high shrub cover. In summary, the mulga grassland set provided reasonable simulation for Lake Mere and Fowlers Gap. However for other sites here was little agreement between simulations and observations.

For the calibrated GRASP parameters, reasonable agreement ($r^2 > 0.6$) occurred at six sites: Lake Mere, Runnymede, Lynwood, Double Dams, East Wygilla and Fowlers Gap (only three independent observations). However, for the long term exclosures, Tundulya and Ivandale, there was little agreement following the initial two observations used for calibration.

At Ivandale the differences between simulated and observed TSDM increased over time suggesting a decline in potential productivity or a change to more rapidly detaching species. At Tundulya, the simulation underestimated the last three observations (from 1989 onwards) suggesting an increase in potential productivity or a change to species with slower detachment rates. The decline in shrub biomass at this site (2,600 kg DM/ha in 1985 to 1,400 kg/ha in 1995) would suggest a decrease in competition for moisture and nutrients and hence an increase in potential productivity.

An average potential regrowth rate was derived from the eight sites (12.3 kg DM/ha/day) which was about 20% lower than that derived for the average of Queensland nature grassland communities (15.0, Day *et al.* 1997) but higher than that derived for mulga grasslands (8.1). These differences may reflect the greater contribution of forbs in NSW rangelands and the less competitive effect of higher shrub/tree densities. Over the whole eight sites the average ‘potential regrowth rate’ parameter in combination with site parameters of run-off, tree density, soil and composition accounted for 68% of the variation (n = 108). With the exception of Tundulya and Ivandale a high proportion of the variation was accounted for at each site (> 70%) and greater than 80% for five of the eight sites. The results suggest that GRASP can be calibrated relatively simply (i.e. one parameter) to simulate a high proportion of variation in standing biomass at a majority of the sites. Calibration of other parameters is likely to improve parameterisation but has not been attempted at this stage.

5.3.6.2 Comparison with SEESAW simulations

In terms of correlation values, GRASP, using either the site-calibrated or the average regrowth parameter, explained a higher or similar proportion of the observed variation at six of the eight sites. SEESAW performed better at Tundulya and Ivandale although both models performed poorly ($r^2 < 0.37$).

Simulations of GRASP and SEESAW were compared at monthly time intervals for both the site-calibrated and average regrowth parameters (Table 22). For the site-calibrated parameter set the models were in close agreement ($r^2 > 0.70$) at seven sites. The Runnymede site had only moderate agreement ($r^2 = 0.61$). As shown in Figures 14 - 21 both models show similar growth pulses and detachment periods. Exceptions are: 1) a small growth pulse at Lynwood not simulated by GRASP parameter sets; and 2) a small growth pulse at Double Dams not simulated by SEESAW. In both cases the observations are in agreement with the SEESAW simulations. At the two sites where both models had poor agreement (Tundulya, Ivandale) there was reasonable agreement between GRASP and SEESAW (e.g. $r^2 = 0.70$ and 0.73 respectively using the average regrowth parameter set). Thus many of the issues raised by Marsden and Hodgkinson (1998) with regard to interpretation of observed data in response to rainfall inputs are also true for GRASP. For example, the major outliers under-estimated by both models were the high TSDM in 1984 at Runnymede; high TSDM after 1989 at Tundulya; high forb yield including medics at Double Dams; and growth at Ivandale in spring 1973. As Marsden and Hodgkinson (1998) suggest, local variation in rainfall between input station and plot location could explain the difference in response.

As stated in Section 5.3.1, the major difference between GRASP and SEESAW is that SEESAW simulates the response of each of five plant guilds in an attempt to capture major species differences, e.g. the fast detachment rates of annual forbs and perennial vegetation. In this study we have used the leaf and stem pools in GRASP to represent fast and slow detaching species. The partitioning of growth between these pools was controlled by a single parameter (p123) that was calculated from inputs used in SEESAW and held constant over time. From this respect the generally reasonable agreement between GRASP and SEESAW simulations may not be unexpected. However, the fact that a constant site-partitioning parameter resulted in the explanation of a reasonable proportion of variation suggests that the agreement between the models is dominated by their similar simulation of the timing and magnitude of growth pulses as a function of rainfall.

Results from the SEESAW simulations (Marsden and Hodgkinson 1998) also show that whilst total biomass may have been simulated well, there was often poor agreement between each of the observed and simulated guilds, e.g. in Lynwood errors in simulation of annual forbs, perennial forbs, C_3 grasses and C_4 grasses cancelled each other out so as to produce a good simulation of TSDM ($r^2 = 0.91$).

Table 21. Mean pasture standing biomass, correlation (r^2) and Root Mean Square (RMS = $(\Sigma(\text{obs-pred})^2/(n-1))^{0.5}$) values for simulations at eight sites in NSW rangelands. Simulation studies were: 1) SEESAW; 2) GRASP with mulga grassland parameter set and TBA = 0.5 m^2/ha; 3) GRASP with mulga parameter set and estimated actual TBA; 4) GRASP with Kinchega parameter set and TBA = 3.0 m^2/ha; 5) GRASP with Kinchega parameter set and estimated actual TBA; 6) GRASP calibrated for each site; 7) GRASP run with average calibrated potential regrowth rate (12.3 kg/ha/day) (Abbreviated file names are shown in italics for archive purposes).

Site	# of obs.	Mean pasture standing biomass (kg DM/ha)								Correlation (r^2)							Root Mean Square						
		Obs. values	See Saw	Mulga		Kinchega		Site paramet.	Average pot. regrowth rate	See Saw	Mulga		Kinchega		Site paramet.	Average pot. regrowth rate	See Saw	Mulga		Kinchega		Site paramet.	Average pot. regrowth rate
				TBA = 0.5 *ara0*	Actual TBA *ara1*	TBA = 3.0 *kin0*	Actual TBA *kin1*	*Soil7*	*Soil8*		TBA = 0.5 *ara0*	Actual TBA *ara1*	TBA = 3.0 *kin0*	Actual TBA *kin1*	*Soil7*	*Soil8*		TBA = 0.5 *ara0*	Actual TBA *ara1*	TBA = 3.0 *kin0*	Actual TBA *kin1*	*Soil7*	*Soil8*
Lake Mere	31	399	421	507	388	472	652	460	626	0.79	0.87	0.88	0.12	0.24	0.85	0.83	151	166	114	310	381	144	276
Runnymede	11	1553	1316	1986	412	1045	715	1729	1788	0.14	0.29	0.51	0.28	0.17	0.69	0.70	864	855	1404	916	1175	552	572
Tundulya	12	766	563	911	177	624	541	765	676	0.37	0.18	0.14	0.20	0.20	0.24	0.24	462	545	782	484	521	471	484
Lynwood	12	310	279	1005	301	650	451	290	543	0.91	0.79	0.77	0.59	0.73	0.75	0.87	57	752	87	400	189	92	256
Double Dams	13	207	191	234	188	386	549	296	259	0.73	0.26	0.29	0.42	0.28	0.87	0.85	309	407	411	402	529	204	201
East Wygilla	13	159[a] 137[b]	183	219	232	434	649	219	305	0.89	0.25	0.24	0.46	0.23	0.75	0.94	94	243	250	368	596	169	242
Fowlers Gap	5	872	795	621	734	437	699	902	857	0.91	0.91	0.91	0.94	0.83	0.98	0.98	169	326	221	380	350	132	117
Ivandale	11	648	451	946	786	569	790	1172	1203	0.25	0.15	0.15	0.40	0.38	0.13	0.12	376	647	502	226	273	800	817
All Sites	**108**	**540**	**476**	**740**	**371**	**560**	**627**	**648**	**727**	**0.64**	**0.55**	**0.19**	**0.46**	**0.18**	**0.69**	**0.68**	**352**	**483**	**550**	**442**	**533**	**355**	**396**

[a] includes chenopod data and relates to SEESAW simulations, [b] excludes chenopod data and relates to GRASP simulations

Table 22. Comparison of GRASP simulations with: 1) observed data not used in the calibration procedure; 2) comparison of GRASP and SEESAW simulations (monthly) with GRASP using site-calibrated potential regrowth rate; and 3) comparison of GRASP and SEESAW simulations (monthly) with GRASP using an average potential regrowth rate (PRGR = 12.3 kg/ha/day). RMS was calculated as $(\Sigma(\text{obs-pred})^2/(n-1))^{0.5}$.

Site	Calibration data removed					Site-calibrated regrowth parameters					Average regrowth parameters			r^2 with actual observations	
	Mean observed TSDM	**Mean GRASP TSDM**	**n**	**r^2**	**RMS**	**Mean observed SEESAW**	**Mean GRASP TSDM**	**n**	**r^2**	**RMS**	**Mean GRASP TSDM**	**r^2**	**RMS**	**GRASP (av. PRGR)**	**SEESAW**
Lake Mere	358	423	29	0.82	143	377	388	142	0.92	88	543	0.92	205	0.83	0.79
Runnymede	1460	1677	9	0.68	616	1217	1330	267	0.60	376	1382	0.61	395	0.70	0.29
Tundulya	803	812	10	0.25	501	466	635	292	0.58	249	539	0.70	166	0.24	0.37
Lynwood	267	247	10	0.61	101	252	234	80	0.58	111	461	0.72	244	0.87	0.91
Double Dams	49	71	11	0.70	166	141	257	63	0.85	171	213	0.91	126	0.85	0.73
East Wygilla	42	140	11	0.71	185	154	172	53	0.81	103	259	0.96	149	0.94	0.89
Fowlers Gap	628	733	3	0.99	164	683	797	58	0.86	188	752	0.88	152	0.98	0.91
Ivandale	615	1251	9	0.23	894	527	1212	96	0.74	790	1240	0.73	815	0.12	0.25
All Sites	**463**	**596**	**92**	**0.66**	**378**	**611**	**784**	**1051**	**0.74**	**347**	**790**	**0.75**	**347**	**0.68**	**0.64**

5.3.6.3 Summary

The following key points can be summarised from the data presented in this report and that of Marsden and Hodgkinson (1998):

1) The comparison of existing GRASP parameter sets with observed data provided a reasonable independent validation at Lake Mere ($r^2 \sim 0.88$) and to a lesser extent at Lynwood and Fowlers Gap. The Kinchega parameter set was in reasonable agreement at only one site, Fowlers Gap, and to a lesser extent Lynwood (Table 21).
2) Calibration of the potential regrowth parameter in GRASP using the first two growth-pulse observations of each time series (and derivation of an average across the sites) substantially increased the amount of variation explained in TSDM across all sites (r^2 0.55 $\rightarrow$ 0.68).
3) For the majority of sites, simulated TSDM from both GRASP and SEESAW models were highly correlated (five sites with $r^2 > 0.80$) suggesting that GRASP can be parameterised to capture the major growth and detachment pulses simulated by SEESAW.
4) The observed data sets compiled for the NSW rangelands highlight the difference in species (plant guilds) in terms of functional parameters, particularly in terms of senescence and detachment rates and probably in terms of the effects of grazing history. The large variation in species attributes such as detachment rates results in large differences in TSDM. Thus the parameterisation of a spatial model from plot or paddock data is likely to be more difficult for NSW rangeland communities than for pasture communities with more uniform species composition (e.g. tropical perennial grasslands).
5) TSDM at some sites/times was well simulated by SEESAW whilst the simulation of individual guilds was poor.
6) The spatial version of GRASP has been successfully parameterised for most NSW communities using NDVI data from 1982 to 1993 (Section 7). The analysis reported here supports the view that GRASP can be sensibly parameterised from NDVI in terms of growth pulses. The range of possible detachment rates indicated at the above eight sites emphasises the importance of extensive assessment of TSDM using spider mapping (Section 5.3.6.3).

5.3.7 Conclusion

The major issue addressed in this report was whether GRASP could adequately simulate observed standing pasture biomass for eight sites in NSW rangelands relative to the performance of the SEESAW model. Existing parameter sets were tested but independent validation was only achieved on a few sites. GRASP was then calibrated to the first two TSDM in each time series using the single parameter potential regrowth rate. Other site parameters (available soil water, tree density, species composition) were estimated from inputs used in SEESAW. The use of a calibrated site-specific regrowth parameters or an average across the eight sites explained a reasonable proportion of variation ($r^2 > 0.69$) for six sites. Comparison with SEESAW simulations, without further calibration, indicated that GRASP and SEESAW were in reasonable agreement ($r^2 > 0.70$) for seven sites and very close agreement ($r^2 > 0.88$) for four sites. Whilst GRASP does not attempt to represent the variation in behaviour of plant guilds over time that SEESAW does, nevertheless, for sites of known composition, GRASP can represent a similar proportion of variation in TSDM as SEESAW. Hence it is recommended that there is currently little potential benefit to be gained from the inclusion of the SEESAW model within the Aussie GRASS modelling framework, and that the GRASP model is the preferred option in terms of both simulation performance and input data requirements.

6 Spider mapping and related fieldwork

6.1 Introduction

The Southern Pastures sub-project area is shown in Figure 22. The area occupies the southern semi-arid rangelands of Australia that, at least in part, are influenced by winter rainfall. These include the open woodlands and chenopod shrublands. Intensive agricultural areas, including the wheat belts in WA, SA and the agricultural areas of western NSW, were excluded.

Field data were considered essential to enable the spatial Aussie GRASS model to be calibrated and validated. The spider mapping technique and data processing, described in detail by Wood *et al.* (1996) and Hassett *et al.* (2001), were adopted as the basis for the collection of this field data. While each of the State's involved in the Southern Pastures sub-project (NSW, SA and WA) aimed to collect essentially the same core data (pasture biomass, edible bush biomass and tree/shrub basal area), slight differences existed in the application of the spider mapping technique. States also varied in the range of data collected for specific reasons, e.g. NSW collected data on run-on/run-off areas to assist in assessing the applicability of the CSIRO SEESAW model. NSW also collected data on land condition for reasons peripheral to Aussie GRASS.

Raw data files collected in each States were edited, corrected and processed using various forms of regressions, before being provided to NR&M in Excel spreadsheet format, for use within the spatial modelling framework. Additional information is provided in this section regarding variations and/or additions to data collection and processing undertaken within this project.

6.2 New South Wales

6.2.1 Climate and seasonal conditions

The NSW Southern Pastures area, as defined for this project, is shown in Figure 23. The area includes the semi-arid and arid rangelands of western NSW and the native pastures of the Riverina Plain. As can be seen from Figure 23, median annual rainfall ranges from approximately 150 mm in the far north-west to approximately 425 mm in the central east. Rainfall seasonality can be roughly divided at the 32^0 latitudinal line. To the north rainfall is largely summer dominant and to the south largely winter dominant.

Much of the Southern Pastures area was in drought during the first sampling season in September to November 1998. This can be seen in Figures 24 and 25 that show extremely low relative rainfall and pasture growth in the six-month period up to December 1998.

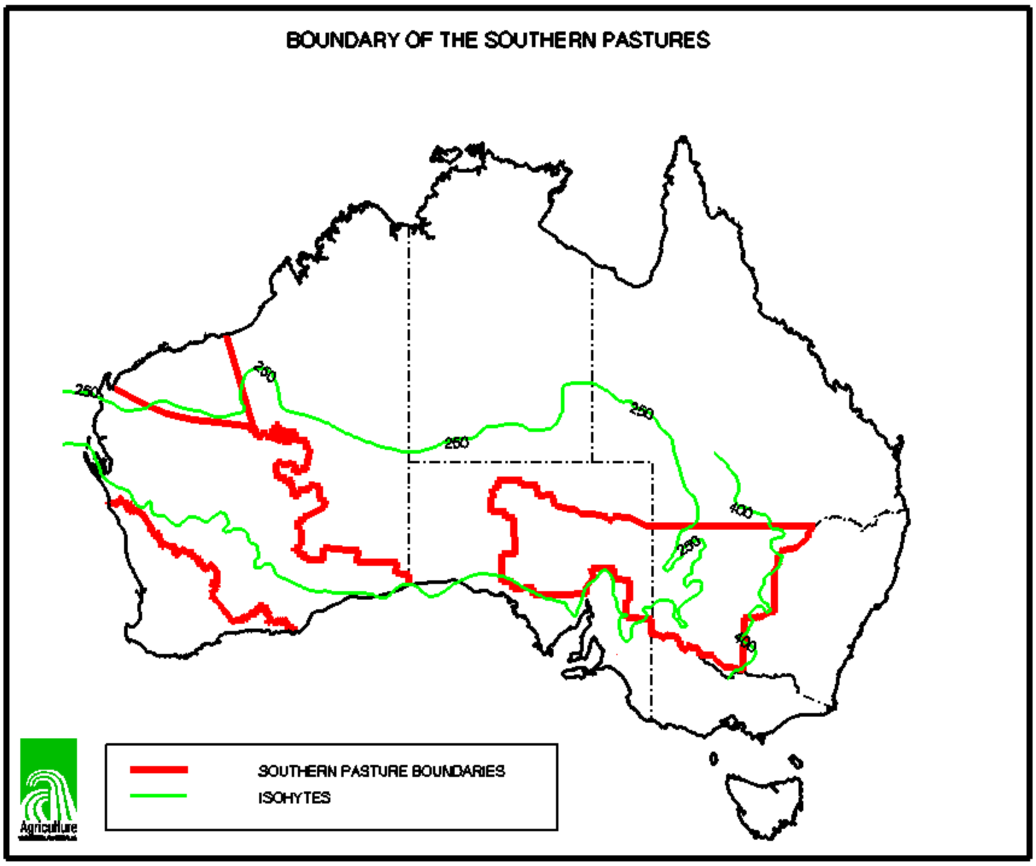


Figure 22. The Southern Pastures sub-project area of southern Australia with 250 and 400 mm annual rainfall isohyets overlaid.

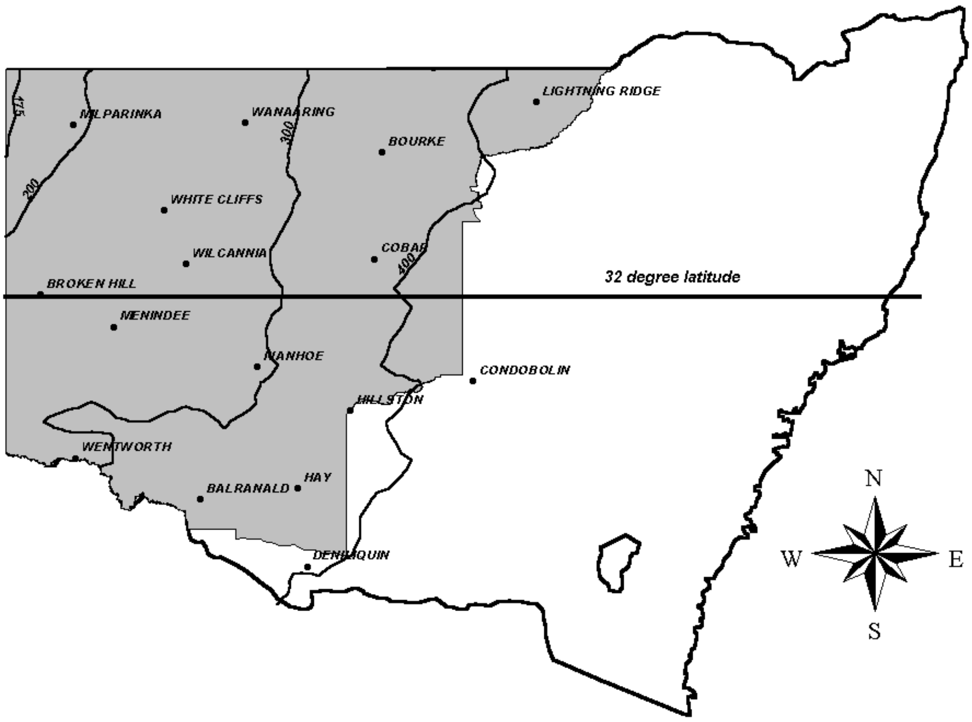
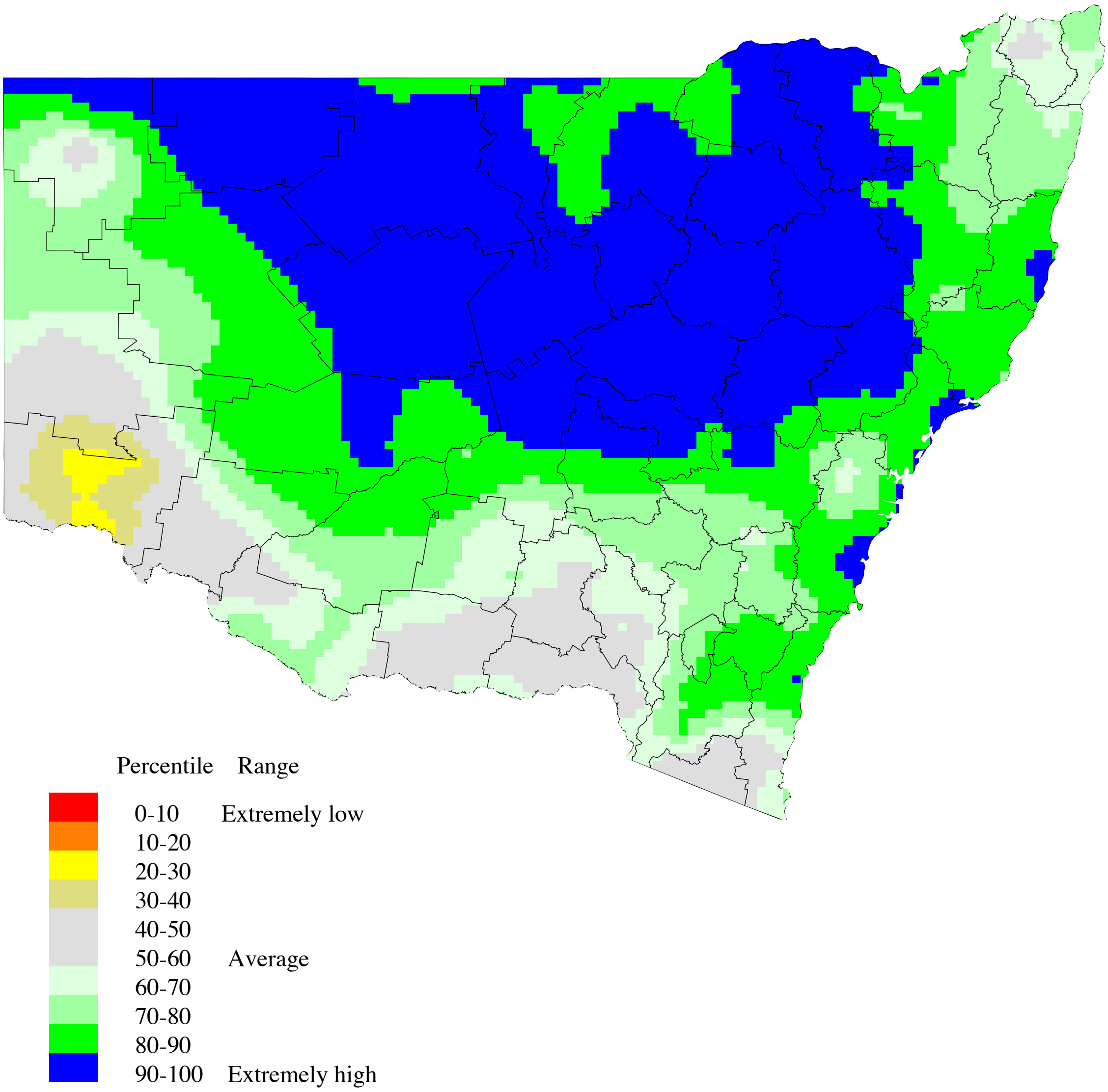


Figure 23. The location of rainfall isohyets within the Southern Pastures area of NSW (shaded area), and the 32° latitudinal line. The latter roughly divides areas to the south with increasing influence of winter rain from those to the north with increasing influence of summer rain.

Rainfall Relative to Historical Records

NSW - July to December 1998



Produced by the Aussie GRASS project funded by the National Climate Variability Program and the NSW Departments of Agriculture and Land and Water Conservation.
Rainfall Data is supplied by the Bureau of Meteorology, Melbourne.
Real-time data may contain reporting errors and omissions.

Figure 24. NSW rainfall for the six months to December 1998 relative to the historical record.

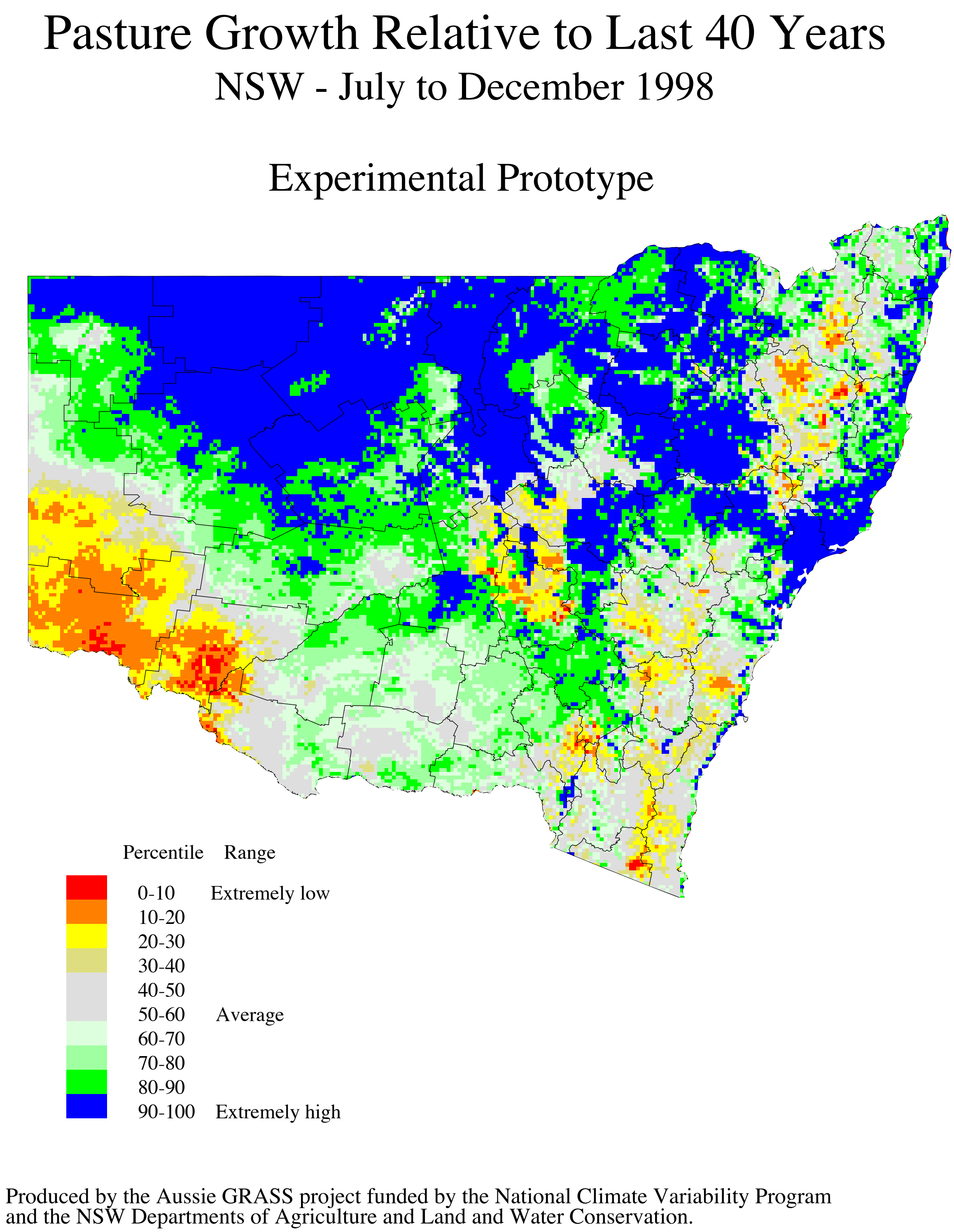


Figure 25. NSW pasture growth for the six months to December 1998 relative to the historical record.

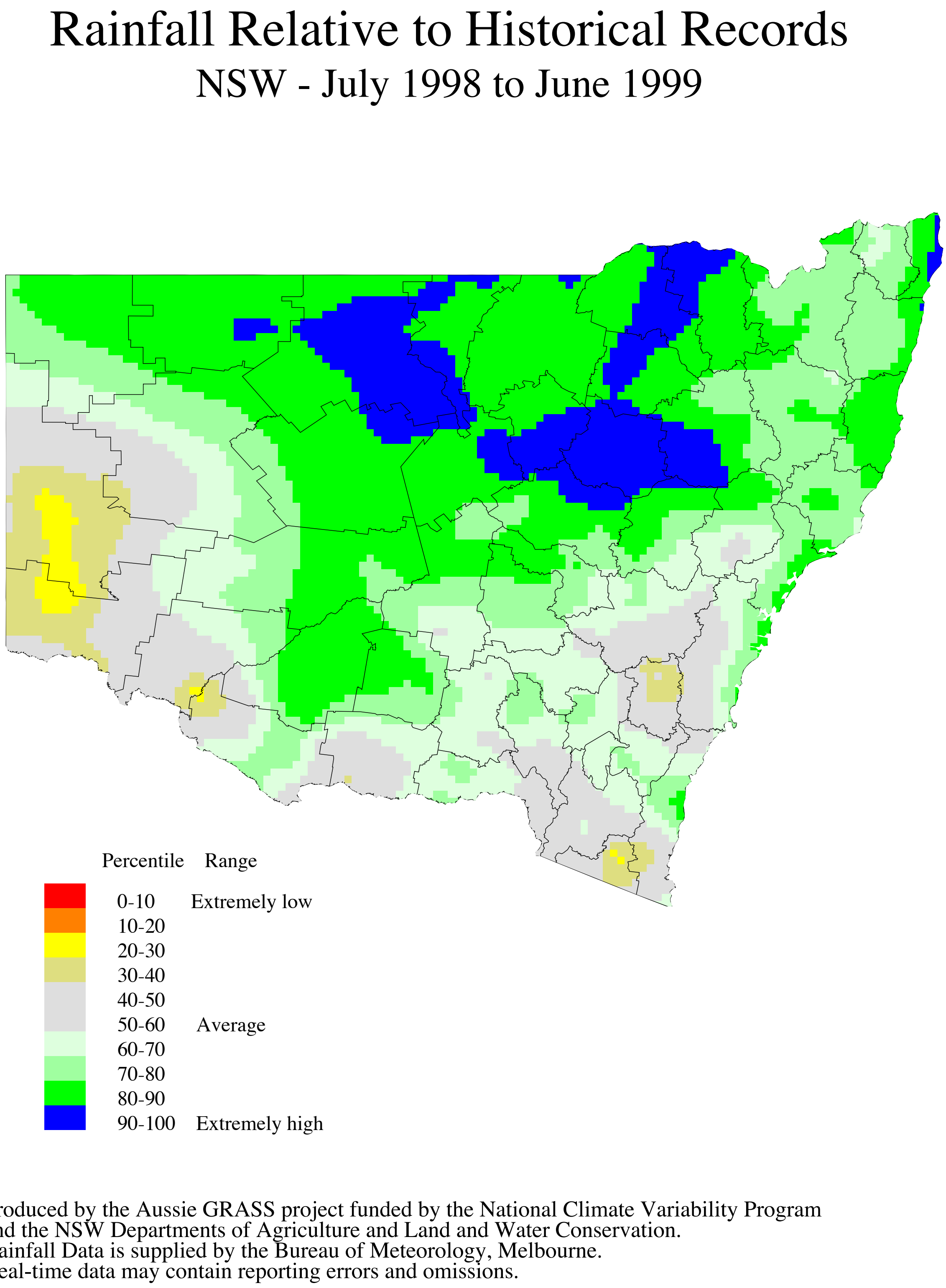


Figure 26. NSW rainfall for the 12 months to June 1999 relative to the historical record.

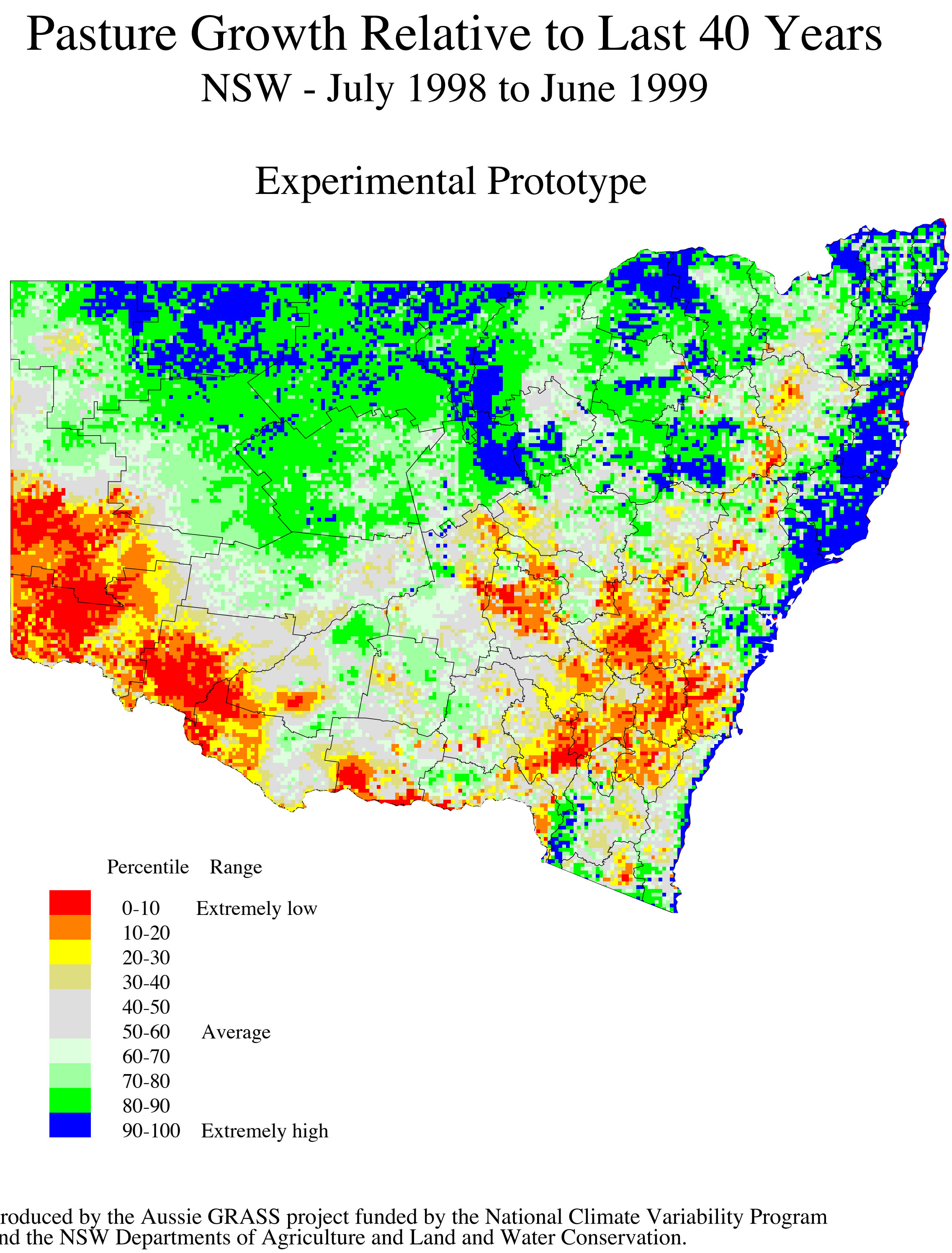


Figure 27. NSW pasture growth for the 12 months to June 1999 relative to the historical record.

Figure 28. Flooding along the Darling River between Bourke and Louth , June 1999.

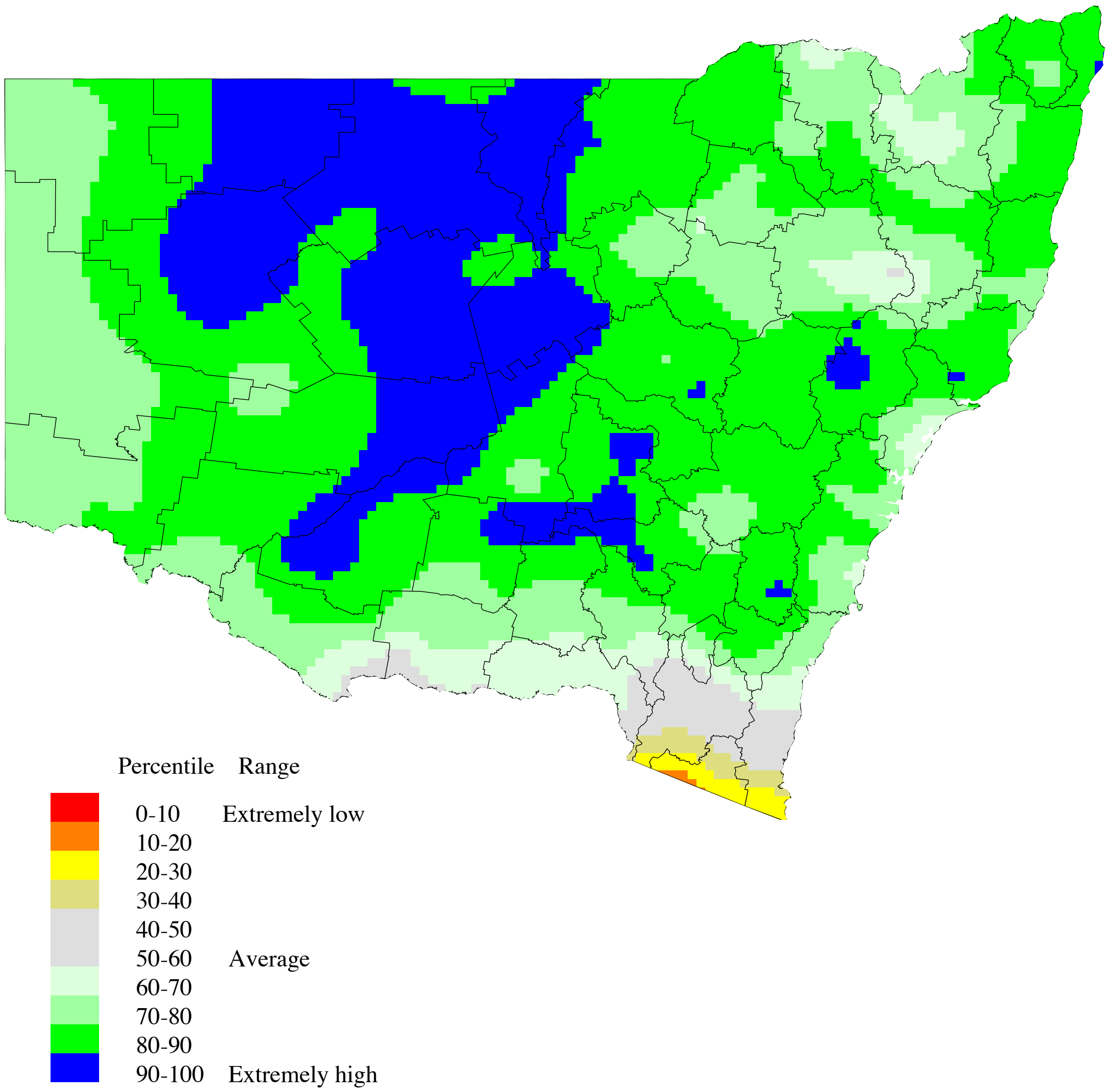
Further field trips were carried out in June 1999, and November to December 1999. As indicated in Figures 26 and 27, seasonal conditions in June 1999 continued to be poor, but by the time of the last trip, many areas had received good rains whilst some northern areas were in flood (Figure 28). As can be seen from Figures 29 and 30, very good rainfall and growth relative to historic records occurred in the later part of 1999. Rainfall and pasture growth for the 12 months to December 1999 are shown in Figures 31 and 32.

6.2.2 Spider mapping

The purpose of the spider mapping field technique (so called because of the 'web-like' appearance of maps showing data locations) is to traverse as large an area as possible and capture vegetation data en-route using rapid assessment techniques. A range of highways, roads and tracks are used to ensure sufficient coverage in any given area. Observations are frequently calibrated using more precise field techniques

It was realised by the collaborators in the NSW and SA portions of the Southern Pastures sub-project that modifications were required to the original spider mapping method. These changes were to allow for the restricted time and resources available and differences in the vegetation structure between the Southern Pastures and Queensland, in particular, the prominence of woody shrubs, the dominance in many areas of perennial chenopods, and the influence of winter annual growth in the pasture. In addition, a new Windows based software was to be developed to enable more flexibility in data capture and system configuration.

Rainfall Relative to Historical Records
NSW - July to December 1999



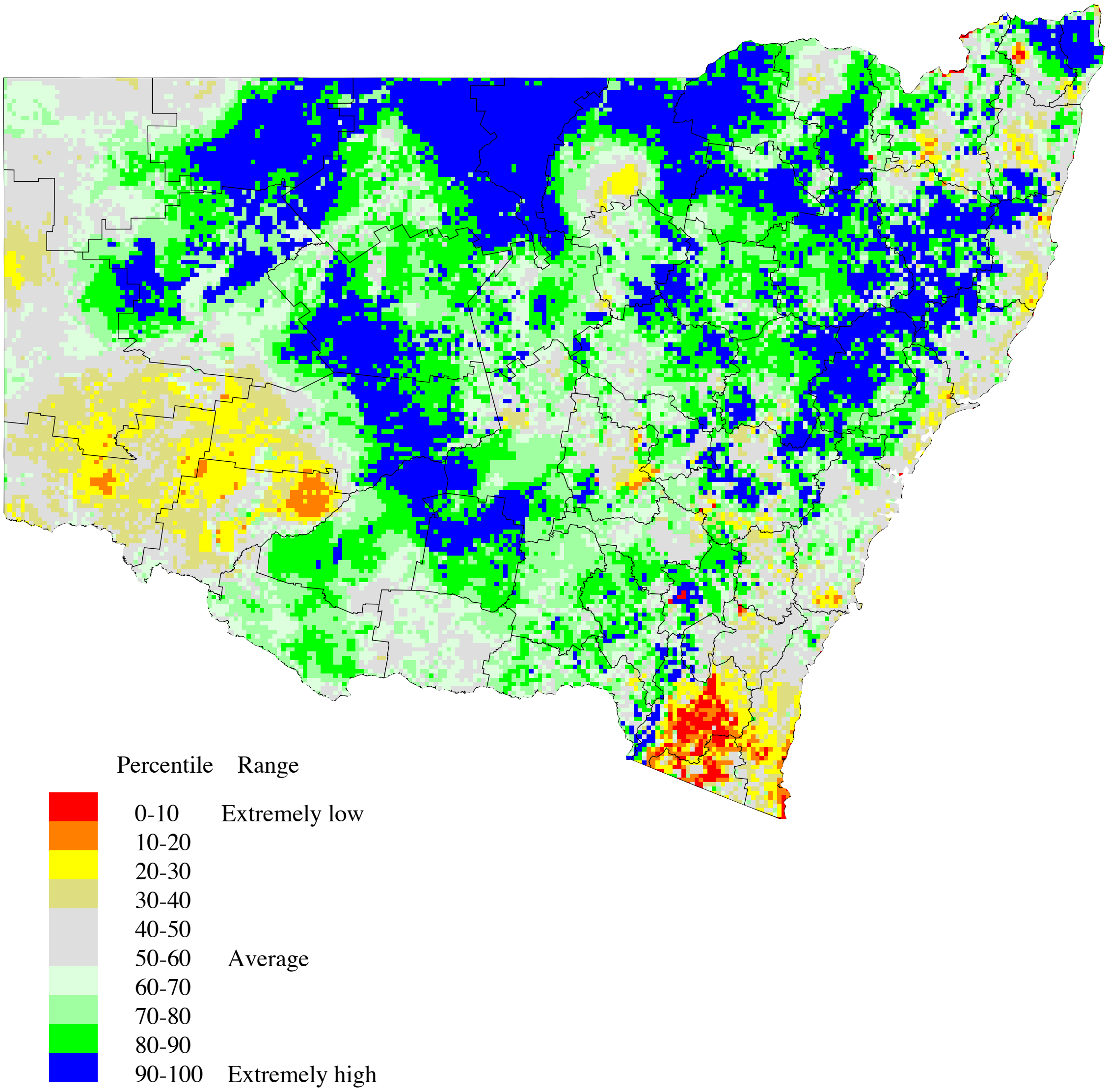
Produced by the Aussie GRASS project funded by the National Climate Variability Program and the NSW Departments of Agriculture and Land and Water Conservation.
Rainfall Data is supplied by the Bureau of Meteorology, Melbourne.
Real-time data may contain reporting errors and omissions.

Figure 29. NSW rainfall for the six months to December 1999 relative to the historical record.

Pasture Growth Relative to Last 40 Years

NSW - July to December 1999

Experimental Prototype



Produced by the Aussie GRASS project funded by the National Climate Variability Program and the NSW Departments of Agriculture and Land and Water Conservation.

Figure 30. NSW pasture growth for the six months to December 1999 relative to the historical record.

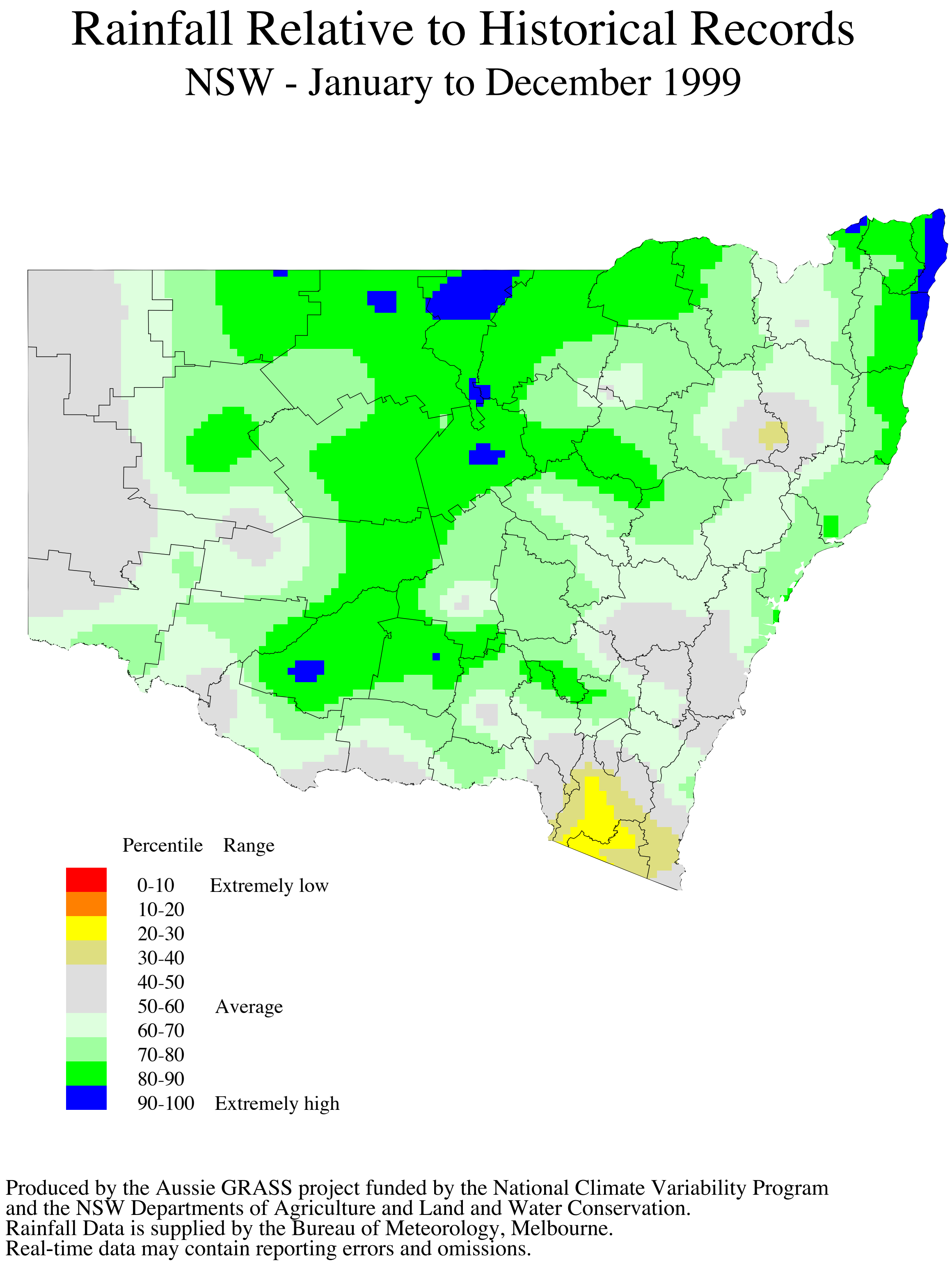
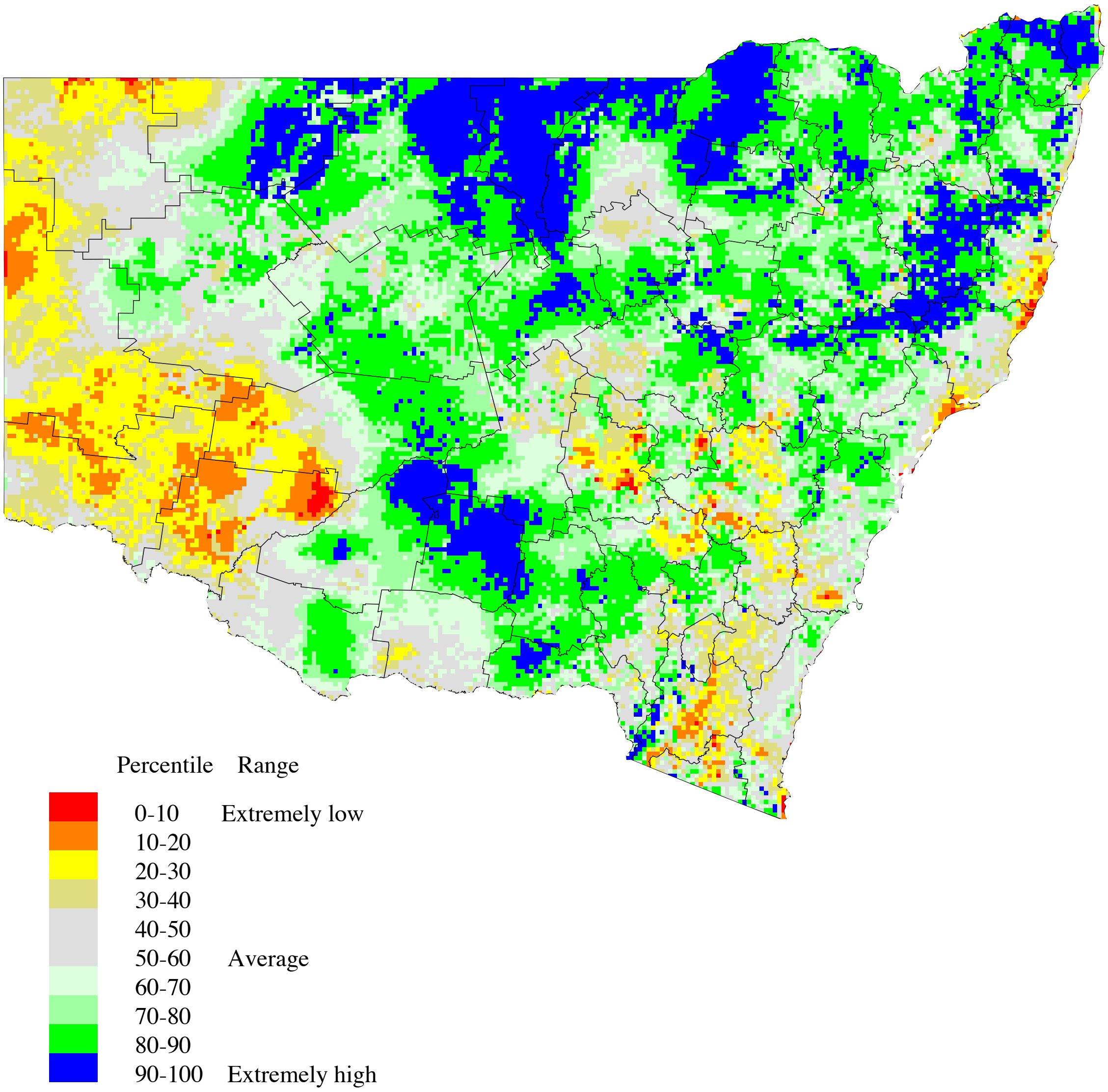


Figure 31. NSW rainfall for the 12 months to December 1999 relative to the historical record.

Pasture Growth Relative to Last 40 Years
NSW - January to December 1999

Experimental Prototype



Produced by the Aussie GRASS project funded by the National Climate Variability Program and the NSW Departments of Agriculture and Land and Water Conservation.

Figure 32. NSW pasture growth for the 12 months to December 1999 relative to the historical record.

In April 1998 officers from NSW Department of Land and Water Conservation, NSW Agriculture and the Department of Environment, Heritage and Aboriginal Affairs SA, spent two days in the field in the Cobar area, together with one of the field officers from NR&M who had carried out the original spider mapping in Queensland. In addition to gaining experience in the method used in Queensland and evaluating its applicability to vegetation communities in western NSW, the design of the new software was discussed and planned. Changes to the original spider mapping method (Wood *et al.* 1996 and Hassett *et al.* 2001), are described in Clipperton and Bean (2000, 2001).

Planning of field trip routes in NSW was based on the intent to capture a wide temporal and spatial data set. Based on the objectives of the Southern Pastures sub-project, priority was given to those vegetation communities that were believed, due to their unique nature, to be the most difficult for GRASP to model. Consequently the northern floodplains, comprised largely of C4 grasslands, were given lowest priority.

To maintain observer consistency a single observer recorded the majority of observations. An average speed of 80 km/hr was maintained on sealed roads and 60 km/hr on unsealed roads. Areas of improved pasture or cropped areas were excluded.

6.2.2.1 Field data capture software

The Windows 95 based software called ‘CIGS’ (Climate Impacts and Grazing Systems) was developed for the Aussie GRASS project by Geonautics International Pty. Ltd., Brisbane. CIGS is a general-purpose data acquisition and logging package that is designed to be run in the field on a Windows 95/NT notebook computer with a global positioning system (GPS) attached. The application reads in data from the GPS and plots the current position of the user on a geotiff background map or image. As the user moves along, predetermined fields of data are captured by activating the relevant function key and adding data in a predefined format. The geotiff images used were Landsat TM satellite images. The software also has the capability of running with one or more vector overlays. A Garmin 75 non-differential GPS was used.

Output data files generated by CIGS are in a comma delimited ASCII format so as to enable transfer to other packages with ease. Data logged in the current session can be interrogated within the software.

A power board was built to allow the computer, the GPS and other equipment to run directly from the battery of a Toyota Landcruiser used in the surveys.

The CIGS software has the capability of recording up to 24 variables, each of which can be allocated to a function key (F1 - F12) or ‘shift + function key’. Each time a function key is activated the software records: the date and time of recording, the coordinates for that location from the GPS, the variable being recorded, and the values entered by the operator. Each function key is configured according to the data that is to be recorded for that variable, the name of the recorder, the colour of the dot that is to appear on the screen in the position determined by the GPS, and the size of the dot. The configuration options allow for data on each variable to be entered into a specified number of fields, each with a specified name, number of characters and nature. Function keys used in the spider mapping in NSW were:

F1	Pasture Yield, Recorder 1,
F2	Pasture Yield, Recorder 2
F3	Transect Site
F4	Harvest Site
F5	Chenopods, Recorder 1
F6	Chenopods, Recorder 2
F7	Trees/Shrubs, Recorder 1
F8	Trees/Shrubs, Recorder 2
F9	Land Condition
F10	Run-on/Run-off
Shift + F1	Fire scar
Shift + F2	Comments
Shift + F3	Cropping.

The GPS and software were set to record coordinates in Transverse Mercator projection and Australian Geodetic datum 84. The 144^0 longitude formed the dividing line between UTM Zone 54 to the west and UTM Zone 55 to the east. In preparing satellite images to load into the CIGS software, boundaries of the images were designed so that each image was wholly within one or other of these zones. Images were prepared by the Agricultural Research Management (ARM) Unit of Resource Information Services of NSW Agriculture in Orange. A standard false colour image (RGB 432) was broken down into tiles based on the 1:100,000 topographic maps of NSW and restitched together in blocks of 3 x 3 to produce 16 geotiff images, each of approximately 36 Mb in size:

Milparinka	Ursino
Yantabulla	Enngonia
Angledool	Broken Hill
Wilcannia	Barnato
Cobar	Menindee
Manara	Ivanhoe
Nymagee	Mildura
Balranald	Deniliquin.

In addition to the images, the ARM Unit in Orange prepared three separate vector overlays for each image of:

- 10 km grid (black);
- the land system boundaries (black) based on data from DLWC; and
- rivers and creeks (blue), roads (yellow) and railway lines (red) supplied by AUSLIG.

These overlays could be displayed singly or in combination over the relevant image.

Prior to the first field trip laminated colour maps were also prepared of each image to be traversed, with the information from each overlay incorporated and a legend for all the land systems in that particular image area. In practice these maps were not used in the field and so were not produced for images to be traversed in subsequent trips.

6.2.3 Descriptions/methods for variables recorded

6.2.3.1 Pasture yield

Pasture yield was estimated from a four-wheel drive vehicle on a continual basis throughout all traverses. An average of approximately four pasture yield observations was made per kilometre. Figure 33 below shows the distribution of pasture biomass estimates in western NSW. In order to maintain a standard approach to pasture observations the following practices were established:

- where possible, observations were made in an area more than fifty metres from the road but no more than two hundred metres;
- all observations were made through the same area of the side window of the vehicle;
- observations were made in good light; and
- pastures were regularly checked to determine their composition including the presence of medic.

Prior to the commencement of fieldwork a series of photo standards was developed. This involved selecting seasonally representative biomasses in typical vegetation communities of western NSW. At each site a photograph was taken and a minimum of ten half-metre square quadrats clipped. The biomass was oven dried in the laboratory and weighed to determine the actual site biomass. Subsequently, throughout the fieldwork at each calibration harvest site, a photo was taken which added to the photo standard reference system. Figures 34, 35 and 36 show some of the photo standards used for the observations.

Each pasture estimation consisted of up to four characters giving information about the pasture biomass and the pasture composition. The last character in the string was used to represent the composition of the pasture according to the following thresholds:

1) dominated by annuals (>50%);
2) dominated by perennials <20 % perennial grasses;
3) dominated by perennials 20-40 % perennial grasses;
4) dominated by perennials 40-60 % perennial grasses;
5) 30-60% non edible plants i.e. copperburrs; and
6) 60 % non edible plants.

For example, a recording of '403' indicated a biomass estimate of 400 kg DM/ha, dominated by perennials with approximately 20-40% of these being perennial grasses.

Yield estimates were entered into the relevant daily log file using the F1 and/or F2 keys. The majority of observations throughout NSW were made by the same observer with contributions from two other observers. All observers noted an increase in estimation skill with experience and regular feedback from harvest sites.

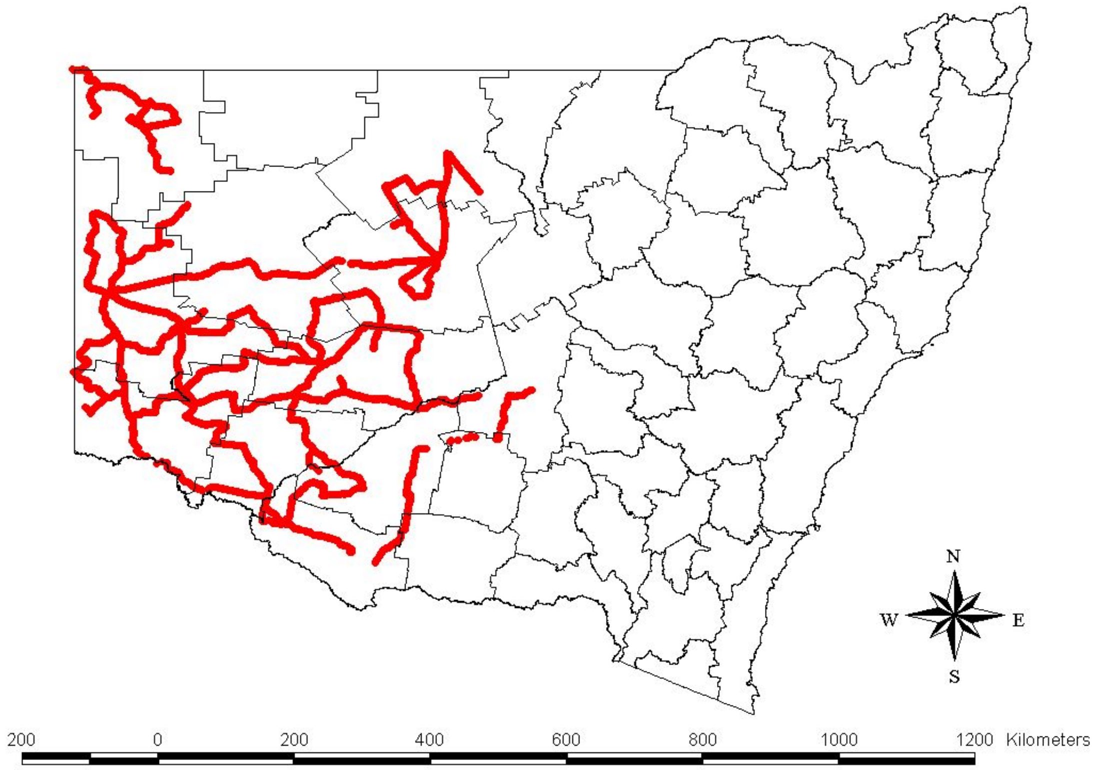


Figure 33. Location of the 19,646 spider mapping pasture biomass observations within NSW. Internal boundaries are Rural Lands Protection Board (RLPB) districts.

Figure 34. Low biomass (8 kg DM/ha) photo standard.

Figure 35. High biomass (2350 kg DM/ha) photo standard – Mitchell grasslands.

Figure 36. Photo standard for *Sclerolaena* spp.

6.2.3.2 Harvest Site

Biomass estimations were calibrated by obtaining data from selected sites where pasture was estimated, clipped, dried and weighed. The harvest sites were selected to represent the range of vegetation communities and biomasses being surveyed on the particular day. At each site an estimation of the biomass was made by each observer and a minimum of 10 half-metre square quadrats cut, the material placed in bags and weighed, then delivered to the laboratory for oven drying and weighing (Haydock and Shaw 1975). All data collected at each site were recorded on a 'Harvest Site Field Data Sheet' (Figure 37). Where high spatial heterogeneity was found in the pasture community, more than 10 quadrats were cut.

At each site a photo and slide were taken at a point marking the beginning of the line at which quadrats were cut. A unique site number was entered into the daily log file together with the observers' estimates. The number of quadrats cut, observers estimations, three dominant species, % cover, % grasses/forbs and % perennial grass cover were all recorded on the data sheet.

Quadrats were cut using hand and electronic shears to a standard height of approximately one cm above the ground. In many cases medic burr was collected at ground level as it contributed significantly to the pasture biomass.

6.2.3.3 Chenopods

Chenopods were recorded in all areas where chenopods were present in densities down to as low as 5 plants per hectare. In many areas chenopods form a lower shrub layer in *Acacia* and *Casuarina* woodlands whereas in other areas, such as the downs country in the far west, they are the dominant strata in the community. Figure 38 shows the distribution of chenopod observations within the Southern Pastures area of western NSW. The following species were measured:

- Bladder saltbush (*Atriplex vesicaria*);
- Black bluebush *(Maireana pyramidata*);
- Pearl Bluebush (*Maireana sedifolia*);
- Cotton bush (*Maireana aphylla*); and
- Old man saltbush (*Atriplex nummularia*).

Other perennial bluebush and saltbush species, similar in growth habit and morphological characteristics, were estimated using the above species as standards. In some areas the density of non-palatable chenopods such as dillon bush (*Nitraria billardieri*), nitre goosefoot (*Chenopodium nitrariaceum*) and glasswort (*Sclerostegia* spp.) were also recorded. Non-edible spinifex (*Triodia* spp.) was also recorded in this way.

Harvest Site Field Data Sheet

Site No.	Side of vehicle a/b	UTM	Yeild			Species 3 dom.	% Cover (total spp)	TWW	SWW	SDW	Quads cut No.	TDW	Date	Photo (film/photo No.)	% Grasses & Forbs	Per. Gr. cover	Notes
			Rob	Steve	Judy												
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											
		E. N. Z				1. 2. 3.											

a = drivers side. b = passengers side.

Figure 37. Data sheet used to record data from harvest sites.

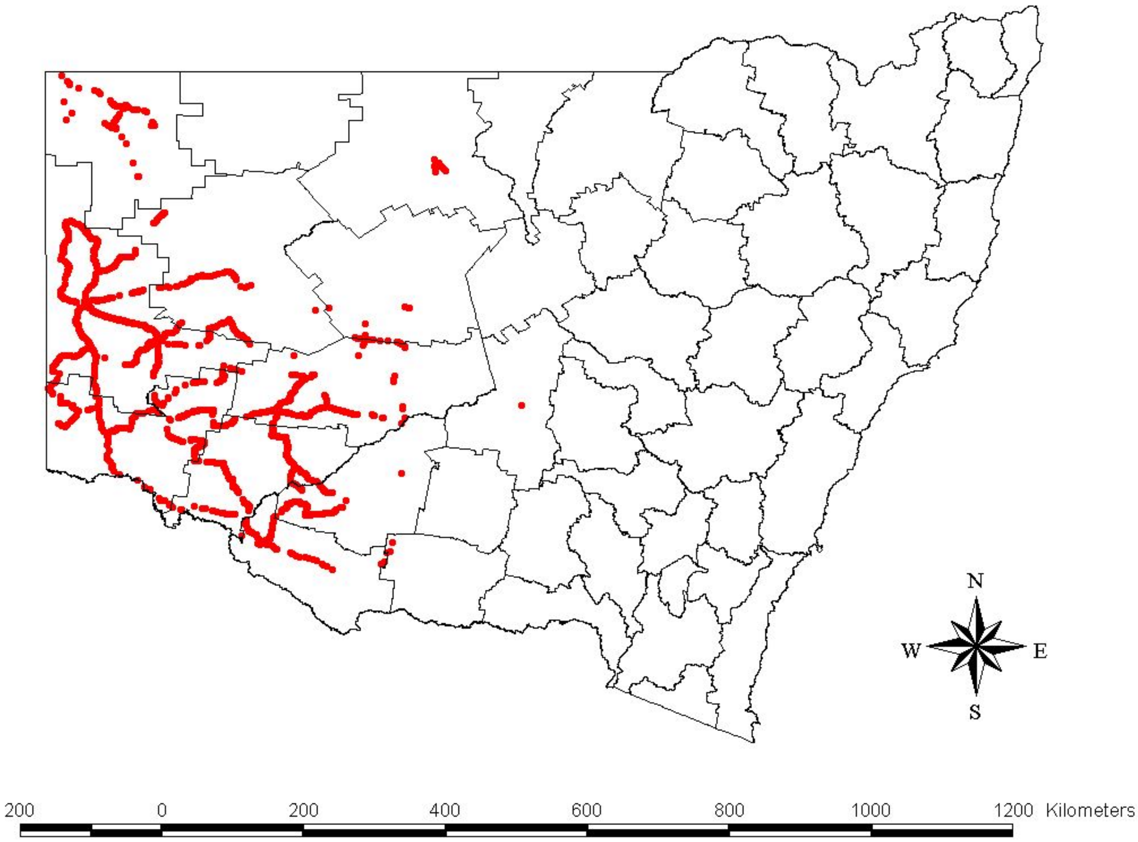


Figure 38. Location of the 3,272 spider mapping chenopod biomass observations within NSW. Internal boundaries are Rural Lands Protection Board (RLPB) districts.

In many areas there were mixed stands of perennial chenopods, i.e. saltbush and bluebush occurring together. In this instance codes designating the mix of these were used. For example, a code of 'bb' meant that the community was entirely of bluebush but a code of 'bs' meant that the community was dominated by bluebush but contained significant amounts of saltbush.

The required input for edible chenopods for the modelling framework was kilograms per hectare of edible leaf material. In order to determine these values four main steps were undertaken:

1) establishment of photo standards of individual bushes with known edible leaf material for each of the representative groups of perennial chenopods;
2) establishment of photo standards of chenopod communities with know densities for each of the representative groups of perennial chenopods;
3) application of photo standards to any chenopod community to derive a density and standard used; and
4) calculation of actual weights for the plant community.

The establishment of photo standards of standard bushes was derived by the following process:

- selection of edible species to be assessed;
- typical communities of these selected species were surveyed to determine average bush size, community densities and composition;
- typical 'standard bushes' of black bluebush, bladder saltbush and old man saltbush were selected;
- the maximum height and width of the selected 'standard bushes were measured along with a rating of the leafiness and leaf turgor of the plant (ratings were estimated out of 5);
- the 'standard bushes' were then scaled, photographed and all leaves, flowers, fruiting parts and small stems (to a diameter of approx. 1 mm) plucked to simulate grazing of all edible parts of the plant; and
- the 'grazed' material was oven dried for 48 hrs at 80 degrees Celsius and weighed; these weights were then recorded on the 'standard bush' photo standard (e.g. Figures 39, 40 and 41) and the labelled photos placed in an A4 photo album in ascending order of biomass.

Where a large variation was evident in bush size, for example with black bluebush, two standards were used – one representing the larger bushes and one the smaller bushes. The smaller 'standard bush' of black bluebush gave 540 grams of edible leaf material whereas the larger one gave 1,071 grams of edible leaf material.

Figure 39. Black bluebush (*Maireana pyramidata*) photo standard - total grazed material weight = 540 gms.

Figure 40. Bladder saltbush *(Atriplex vesicaria*) photo standard - total grazed material weight = 662 gms.

Figure 41. Preparation of bladder saltbush photo standard for clipping.

The establishment of photo standards of chenopod communities was derived by the following process:

- Suitable chenopod communities within the Southern Pastures area were identified. Areas of these communities that appeared to be homogeneous in density and representing a range of densities were selected and photographed. The range varied according to the species. For example, old man saltbush communities ranged up to approximately 2,000 plants per hectare whereas bladder saltbush communities ranged from 3,000 to 12,000 plants per hectare.
- In each area selected, a minimum of four parallel 100 m transects were conducted using a 1 metre wide Jessup stick. The observer walked the transect line holding the Jessup stick in front. A bush was counted as a 'hit' if it had 50% or more of its canopy within the one m span of the stick. Bushes greater than 2 m in diameter were counted as a hit if the 1 m wide span of the stick was totally occupied by the canopy. All plants greater than 10 cm were recorded using this method. An average density for the four transects was used to label the photo standard for that area of the community.
- Photo standards were labelled, categorised and put into an A4 album for quick field reference.

Visual estimates were determined by detecting 'clumps' of foliage. In most instances these clumps were individual bushes but in some cases, particularly in saltbush communities, the clumps were two or more bushes growing closely together. For the purpose of biomass estimation the growth habit was not important.

6.2.3.4 Chenopod calibration sites

During the fieldwork measurement of the density of chenopod communities was carried out periodically using the Jessup stick method described above. These calibration sites were used to correct or adjust chenopod density estimations made on that day. They also served as valuable instantaneous feedback for observers on the accuracy of their estimations.

At each site a minimum of four 100 m transects were conducted. Transects were run parallel to each other and generally at right angles to the direction of the road. Transects were sighted with the use of a compass. The average for the four transects was recorded.

6.2.3.5 Trees/shrubs

Given the dominance of a woody shrub understorey in many areas of western NSW, techniques used previously (Hassett *et al.* 2001) could not be employed. Aside from the vertical tube method, various alternative techniques were tried such as the Bitterlich gauge, the optical wedge and various versions of the crown separation ratio. Given the dense and multi-stemmed nature of the understorey in many areas, none of these techniques proved useful. It was decided to estimate percentage canopy cover as a suitable rapid assessment technique.

Estimates of tree/shrub percentage canopy cover were made from the ground and from the air. Estimates were made every one kilometre from vehicle transects and less frequently from the air. The area observed from the air for each estimation was 200 x 200 m. Estimates were made of the sum percentage canopy cover of trees and shrubs, i.e. upper and lower canopy cover. The total canopy cover could therefore be greater than 100%. Figure 42 shows the distribution of canopy cover assessments made during the survey period.

6.2.3.6 Transect site - calibration

The goal in the calibration transects was to sample areas of trees and shrubs which represented the range of canopy cover (%) occurring in the NSW area of the Southern Pastures and develop a relationship between foliage projected cover (FPC) and tree/shrub basal area.

Eighteen transect sites were selected to represent a range of vegetation communities, varying shrub-tree ratios, a range of total % canopy cover and areas as uniform as possible. In areas in which % canopy cover had previously been estimated from a plane, the transect sites were selected according to the GPS way points entered above areas of apparently uniform tree-shrub cover over an area of approximately one km square. At each transect site a colour photo and a slide were taken and the initial 100 m transect placed perpendicular to the road running out from the photo position and starting at sufficient distance from the road to avoid roadside disturbance.

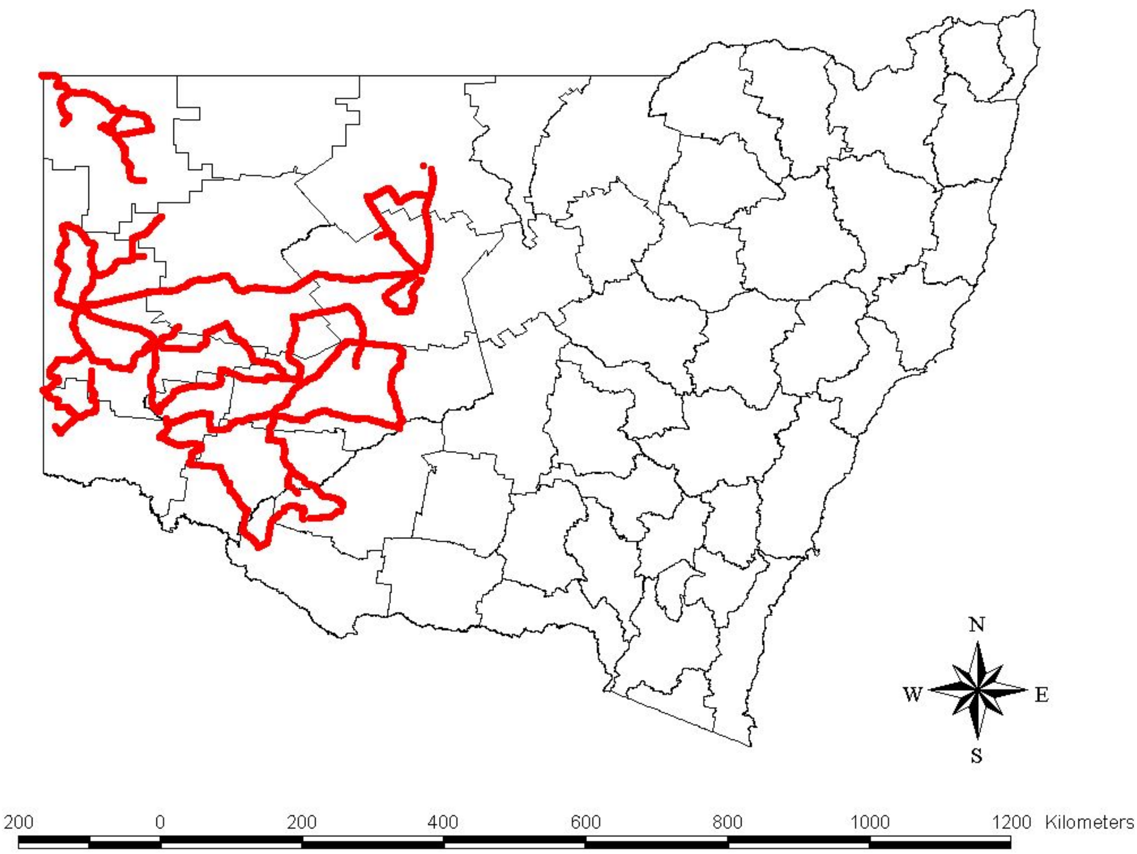


Figure 42. Location of the 5,176 tree-shrub canopy observations within NSW. Internal boundaries are Rural Lands Protection Board (RLPB) districts.

At each 1 m mark on the tape, at which canopy occurred directly above the mark, the nature of the canopy (upper or lower or both) and the percentage green leaf in the canopy were recorded (based on diagrams in McDonald *et al*. 1984). In addition to the canopy, at each 1 m mark on the tape, the understorey was assessed as either grass GL (green leaf), grass DL (dry leaf), forb GL (green leaf), forb DL (dry leaf), tree/shrub litter (detached), Gr/F litter (detached grass and forb litter), bare ground or cryptogam (see Figure 43 for sample data sheet).

A belt transect was then run along the same tape and the circumference of the trunk of each shrub (with multi-stemmed shrubs the circumference of each stem was measured) and tree with ≥ half of its trunk within the band area measured using a piece of string which was then placed on a ruler. For woody vegetation, which at 30 cm above the ground had a single trunk, circumference was measured at this height; for woody vegetation which had one trunk at the base but branched out below 30 cm, the circumference was measured at the highest level of the one trunk; for shrubs with multi stems from the base, the circumference of each stem was measured. For multi-stemmed trees or shrubs, those belonging to the one plant were bracketed in the MS column of the data sheet (Figure 44). Seedlings (< 50 cm high) were given a tick in the SDL column. The width of the belt transect was selected as either 1 or 2 m according to the density of the trees/shrubs at the site.

In relatively uniform areas, one additional transect was placed parallel to, and 100 m from the first transect, and monitored as for the first transect. In less uniform areas a total of three or four 100 m transects were placed and monitored, each parallel to the other transects and at a distance of 100 m from the adjacent transect.

The circumferences from the belt transects were recalculated as basal areas (BAs) and the percentage of canopy 'hits' from the line transects recalculated, in the light of the percentage green leaf, to give FPC.

Even though values of canopy cover at individual 100 m transects at all sites ranged from 0 to 72%, when these values were translated to FPC, the range of values was limited to 0 to 31% for individual 100 m transects and 4 to 25% for average values for all transects at the one site.

Plotting of the average values of FPC and tree/shrub BA obtained at each of the 18 sites gave a linear equation of:

$$y = 0.7371 * x + 9.0879 \qquad (r^2 = 0.19)$$

A polynomial regression produced the following equation:

$$y = -0.1141 * x^2 + 2.7464 * x + 1.6126 \qquad (r^2 = 0.27)$$

The very low correlation values for these relationships were at least in part a result of the narrow range of values of FPC existing in the Western Division of NSW. In the absence of communities with far higher FPC values it would appear very difficult to obtain correlation values similar to those reported for Queensland (Hassett *et al*. 2000). For the same reason, comparison of average values for tree-shrub basal areas measured at each of the 18 transect sites with values for the NR&M spatial tree map of Australia gave very low correspondence ($r^2 = 0.02$).

The relationship between average FPC and average percentage canopy cover at the eighteen sites gave a linear equation of:

$$y = 0.3577 * x + 2.8444 \qquad (r^2 = 0.92)$$

Plotting of data collected at all individual 100 m transects (50) gave a linear equation of:

$$y = 0.4051 * x + 1.4264 \qquad (r^2 = 0.92)$$

6.2.3.7 Land condition

Land condition was assessed to gain additional data on the ability of the land to produce pasture. Assessment was by visual appraisal of the erosion and land capability attributes listed in Table 23 and experience of the observer. These attributes included the amount and severity of erosion, the presence and density of undesirable weeds, pasture diversity, plant health and composition and soil intactness.

6.3 Western Australia

6.3.1 Climate and vegetation

The WA southern pastures area for this project consists of the arid shrublands extending from the southern Pilbara, through the Gascoyne, Murchison and the Goldfields and out to the Nullarbor.

Average annual rainfall is between about 200 and 250 mm. Throughout most of this area, winter rainfall is the most reliable, although tropical depressions and cyclones can occasionally bring high rainfall in summer. The west and south-western parts of this area are winter rainfall dominated. To the east, north east and south east the proportion of summer rain increases, making the seasons generally less reliable than in the western and southern parts, even though some of the former areas have higher average rainfall.

To the north of the WA arid shrublands, in the Pilbara, the higher amount and reliability of summer rain favours perennial grasses. The shrublands are found south of this area, except in locations where deep sand, of low nutrient status, favours spinifex communities. The shrublands contain chenopod (saltbush and bluebush) shrublands, mulga shrublands and shrub covered sandplain country (Burnside *et al*. 1995).

Chenopod shrublands represent some of the most fertile and productive country in the shrublands and occupy about 20% of the total area. In many cases, they occur on alluvial plains, frontages and deltas but they are also found on breakaway slopes, undulating stony plains, level plains and lake frontages. The Nullarbor is a geographically distinct area of chenopod shrublands and was not sampled in the spider mapping process.

Mulga shrublands occupy about 60% of the shrublands and are found on hardpan plains, upslope of the plains on hilly or undulating granite and on stony plains. The soils are often shallow and generally infertile.

Sandplains are found both in small areas amongst other country and also as large contiguous areas, such as in the west Gascoyne. On the more infertile soils, spinifex dominates but in other areas, wanderrie banks, bowgada/wanyu (*Acacia linophylla* and *A. ramulosa*) low woodlands and currant bush mixed shrub pastures are found.

Table 23. Erosion and land capability attributes used to assess land condition. Erosion categories 0, 1, 2, 3 were based on a combination of wind and water erosion categories from Payne *et al*. (1987)

Attribute group	Rating	Comments
Wind erosion	0	No erosion
	1	Litter redistribution and small scalds. Small isolated scalds on which the surface shows some degree of polishing. Redistribution of soil to the margins of the scald, or minor build up of soil material around obstacles.
	2	Large isolated scalds and hummocks. Stripping of the soil surface and build up against obstacles associated with large but generally discontinuous scalds; or, numerous small scalds scattered throughout the site.
	3	Major deflation of soil surface. Active stripping resulting in large continuous scalds with polished and sealed surfaces. Frequent large hummocks against obstacles. In sandy systems major dune drift. Plant cover very sparse to absent.
Water erosion	0	No erosion
	1	Rilling or thin sheeting. Patchy rilling and small gullies affecting small areas or thin sheeting (1 to 2 cm) and breaking of the surface seal on parts of the site. Some redistribution of soil and litter downslope. Much undisturbed ground between affected areas.
	2	Gullies and/or sheeting. Gullies on the lower slopes or more susceptible parts of the site, these being capable of extension to less susceptible areas. The gullies may be associated with extensive but discontinuous disturbance of the soil surface by sheet erosion and redistribution of soil material.
	3	Terracing or extensive gullies. Severe sheeting or terracing affecting nearly all of the site. Redistribution of soil and exposure of subsoil or rock material. The sheeting may be associated with or replaced by very extensive gullying over most of the site.
Capability	H	• evidence of regeneration of desirable species • significant perennial grasses • low erosion hazard - slope low, good cover, soil type • diversity of plant species • area/community in its 'stable state' - cryptogam, perennial grass • no woody weeds, even though significant bare ground
	M	• area in which woody weeds starting to appear • some trees felled
	L	• resource has deteriorated evidenced by • presence of undesirable plant species e.g. boxthorn, dillon bush, woody weeds • dominated by annuals • loss of biodiversity • soil piled up at fences and around plants
	EL	• extreme examples of L.

Data Sheet for Point Transect

Site Number _______________ **Transect Number** _________________ **Direction** ____ ____ **to** ____ ____

	CANOPY				UNDERSTORY											CANOPY				UNDERSTORY									
					Grass		Forb													Grass		Forb							
	UC	%GL	LC	%GL	GL	DL	GL	DL	TR Litter	Gr/F litter	BA	Cryp		Total GL		UC	%GL	LC	%GL	GL	DL	GL	DL	TR Litter	Gr/F litter	BA	Cryp		Total GL
1															51														
2															52														
3															53														
4															54														
5															55														
6															56														
7															57														
8															58														
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43															93														
44															94														
45															95														
46															96														
47															97														
48															98														
49															99														
50															100														

Figure 43. Data sheet used to record data on under and overstorey cover.

Data Sheet for Belt Transect

Site No ______________ Transect No ________________ Direction ___________ to ____________

	MS	Circ	SDL		MS	Circ	SDL		MS	Circ	SDL		MS	Circ	SDL		MS	Circ	SDL
1				51				101				151				201			
2				52				102				152				202			
3				53				103				153				203			
4				54				104				154				204			
5				55				105				155				205			
6				56				106				156				206			
7				57				107				157				207			
8				58				108				158				208			
9				59				109				159				209			
10				60				110				160				210			
11				61				111				161				211			
12				62				112				162				212			
13				63				113				163				213			
14				64				114				164				214			
15				65				115				165				215			
16				66				116				166				216			
17				67				117				167				217			
18				68				118				168				218			
19				69				119				169				219			
20				70				120				170				220			
21				71				121				171				221			
22				72				122				172				222			
23				73				123				173				223			
24				74				124				174				224			
25				75				125				175				225			
26				76				126				176				226			
27				77				127				177				227			
28				78				128				178				228			
29				79				129				179				229			
30				80				130				180				230			
31				81				131				181				231			
32				82				132				182				232			
33				83				133				183				233			
34				84				134				184				234			
35				85				135				185				235			
36				86				136				186				236			
37				87				137				187				237			
38				88				138				188				238			
39				89				139				189				239			
40				90				140				190				240			
41				91				141				191				241			
42				92				142				192				242			
43				93				143				193				243			
44				94				144				194				244			
45				95				145				195				245			
46				96				146				196				246			
47				97				147				197				247			
48				98				148				198				248			
49				99				149				199				249			
50				100				150				200				250			

Figure 44. Data sheet used to record data on tree-shrub trunk circumference.

6.3.2 Spider mapping

Because of the limited resources available for spider mapping in the Southern Pastures sub-project in WA, the decision was made to limit the types of data collected so that the maximum number of data points could be collected. Therefore, the data were limited to estimates of non-woody biomass. Estimates of shrub biomass were not made because of the time needed to properly assess the biomass and concerns over the difficulty in assessing how much of it was available to livestock and sufficiently palatable to be browsed.

WA southern pastures field work was carried out using the CIGS software as in NSW. The GPS used in conjunction with the software was a non-differential Lowrance GlobalNav 212 and all data were captured in WGS84 datum.

Given the reduced range of data types collected in WA relative to NSW, only five function keys were required:

F1 **Pasture TSDM**, recorder 1
F2 **Pasture TSDM**, recorder 2
F3 **Location** (major turnoffs and road intersections)
F4 **Transect TSDM**, transect No., recorder 1 estimate, recorder 2 estimate
F5 **Transect TSDM**, average estimate, actual field wet weight

Traverse routes were chosen to provide a selection of country that most represented an area, although large areas of spinifex grasslands were deliberately avoided. In general, station tracks and Shire roads were used rather than main roads. Vehicle speed was approximately 60 km/h on station tracks and 80 km/h on public roads.

Estimates of TSDM during field traverse were made within a general area of between 50 and 100 m from the roadside. Estimates were made independently from the left hand side of the vehicle by the passenger and from the right hand side by the driver.

Quadrat cuts of TSDM were made at a number of calibration transects each day. These transects typically represented the range of estimated TSDM observed during that day's traverse. At these sites, the vehicle was stopped and an estimate of TSDM at a particular area was made by both the driver and passenger. The non-woody vegetation within each of ten quadrats was then cut at ground level, bagged and weighed in the field. The wet weights from these calibration transects provided feedback to the passenger and driver on the relationship between their TSDM estimates and the wet weight.

The cut samples were taken back to the lab, oven dried and weighed and this data was then used to develop regression relationships between estimated and actual TSDM.

Because of the high rainfall during 1999 (Figure 45), the opportunity was taken to provide nutrient estimates of non-woody biomass as a guide to setting the maximum available nitrogen parameter within the GRASP model. Where it was considered the calibration transects represented close to maximum expected biomass, the oven dry samples for each of the relevant transects were mixed together, ground to small particle size and analysed

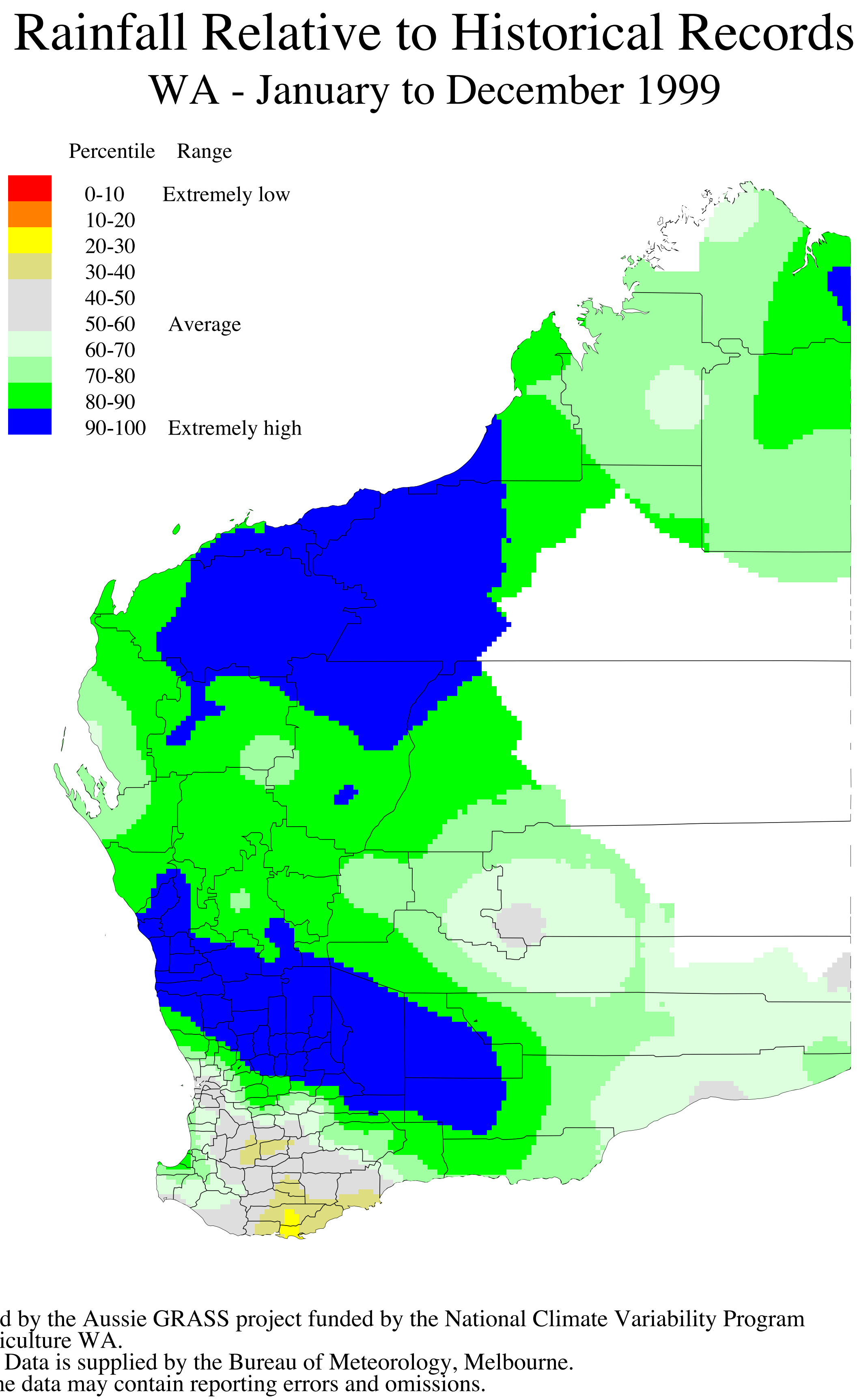


Figure 45. WA rainfall for the 12 months to December 1999 relative to historical records.

for NPK by the WA government Chemistry Centre. The locations at samples were analysed for nitrogen are shown in Figure 46.

6.3.2.1 Field trips

Spider mapping in WA did not begin until 1999. Very wet conditions during the first half of 1999 meant that several planned trips were cancelled and even the first trip was shortened by rainfall and closed roads throughout the area. However, this did mean that during winter 1999 some areas carried close to the maximum non-woody biomass in observed memory.

In all, five field trips were made in 1999 throughout the Upper Gascoyne, Murchison, Meekatharra and north-east Goldfields areas (Figure 47).

6.4 South Australia

6.4.1 Climate and vegetation

The arid rangelands in SA comprise approximately 741,000 km^2. These are areas of native vegetation beyond the agricultural cropping boundary of the 250 mm rainfall zone. Rangelands include pastoral leases, aboriginal lands, parks and reserves, with small areas of military bases and unallotted crown lands.

Rainfall in the rangelands is unreliable, unpredictable, extremely variable and generally less than 250 mm per year. Evaporation rates generally exceed 2,500 mm per year and daytime temperatures in summer exceed 40^{0}C.

The rangelands are characterised by sandy, stony and piedmont deserts and desert clay plains, with some ranges and floodplains. Several major desert rivers flow into Lake Eyre when exceptional rainfall events occur in the Lake Eyre Basin catchment.

There are two main vegetation types in the rangelands, comprising low chenopodiaceous shrublands (*Atriplex* spp. and *Maireana* spp.), and tall shrublands to tall open shrublands dominated by Mulga (*Acacia aneura*) communities. Ephemeral floodout country and open grasslands comprise two other important land types.

Four perennial species characterise the main chenopod shrubland types; bladder saltbush (*Atriplex vesicaria*), pearl bluebush (*Maireana sedifolia*), blackbush (*Maireana pyramidata*) and low bluebush (*Maireana astrotricha*). The northern cattle leases also include Oodnadatta saltbush (*Atriplex nummularia* ssp. omissa), a relatively large unpalatable species. Soil features largely determine the communities. Other chenopod species include Queensland bluebush (*Chenopodium auricomum*) that occurs in swamps and run-on areas on stony tablelands, but is mostly associated with the flood-out country of the major rivers in the far north east of the State. Chenopod sub-shrubs include short-lived *Sclerolaena* spp. which provide nutritious forage when fresh.

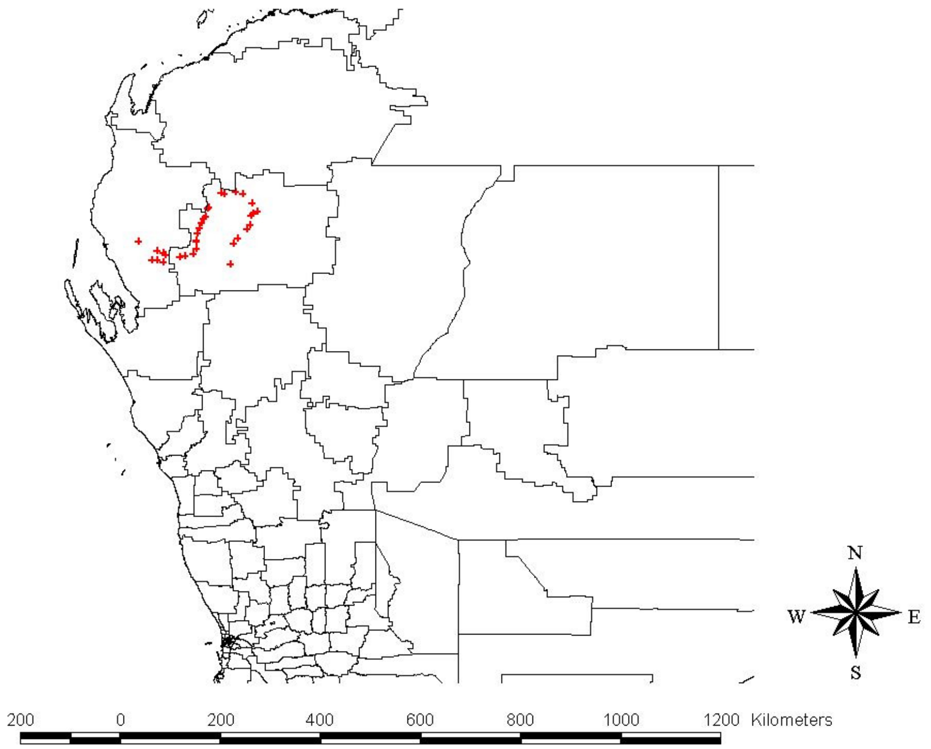


Figure 46. Location of the 35 spider mapping sites at which harvest samples were analysed for nitrogen. Internal boundaries are Statistical Local Areas.

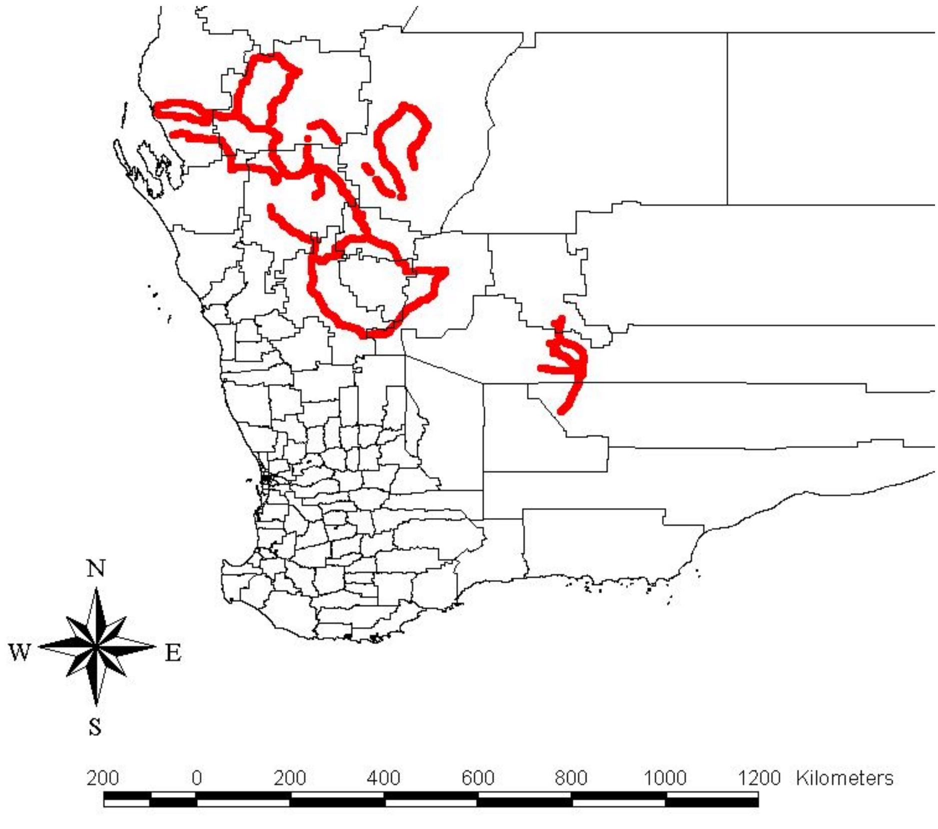


Figure 47. Location of the 28,447 spider mapping pasture biomass observations within WA. Internal boundaries are Statistical Local Areas. (NB only 22,041 of these observations were able to be used in the calibration/validation of the Aussie GRASS model due to the low correlations between calibration harvests and observer estimates – more details are provided in Table 25)

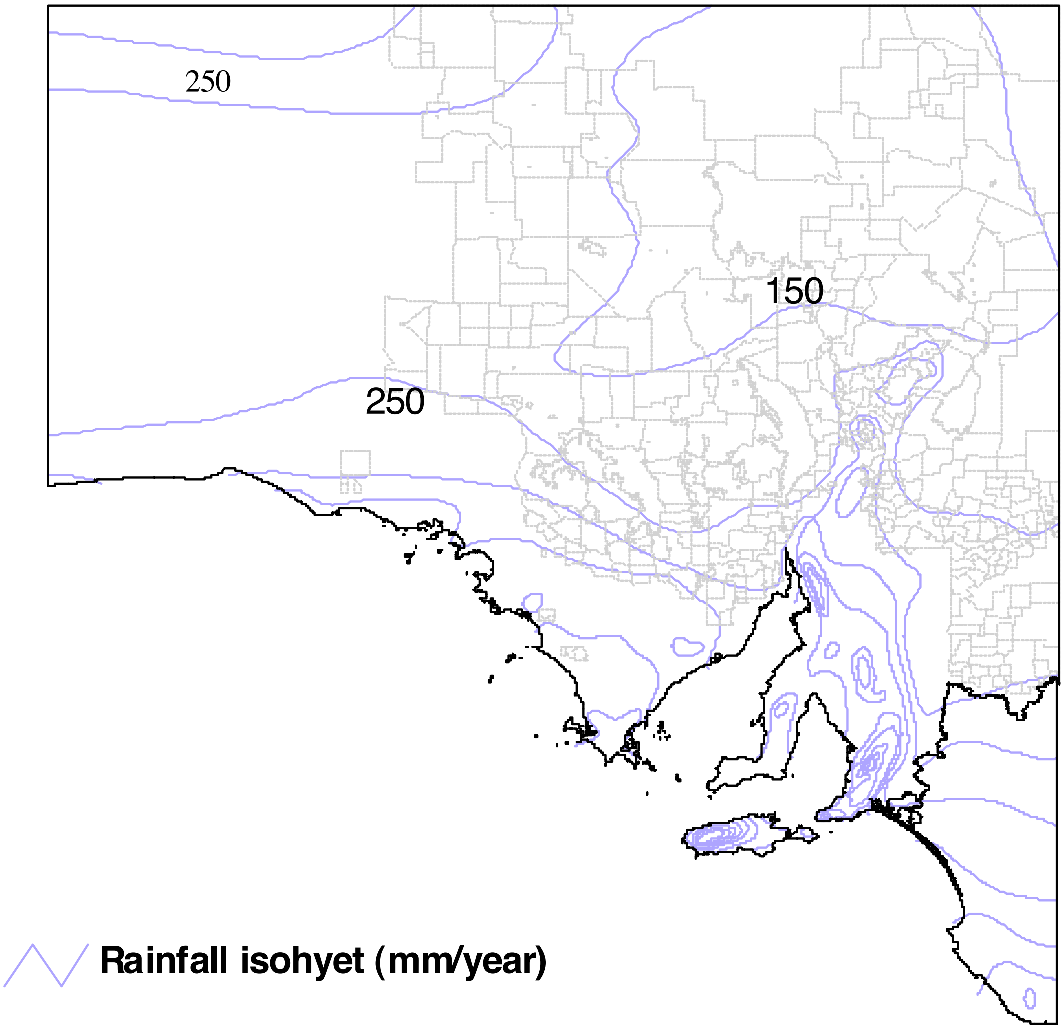


Figure 48. Rainfall isohyets (mm) for South Australia (Source: Australian Rainman software V2.1).

6.4.2 Spider mapping

An initial calibration field trip was conducted in April 1998 in collaboration with the NSW officers of DLWC and undertaking the Aussie GRASS project. Modifications were made to the method of Hassett *et al*. (2000) to account for the variation in vegetation structure and the limited time available for field work. These modifications also allowed for general similarities in vegetation communities between NSW and SA, and for the differences observed in the northern parts of SA. Hence, the spider mapping approached adopted for the Aussie GRASS project in SA was essentially the same as that for NSW but with an emphasis solely on grass and forb biomass.

Field work began in 1999 using the CIGS software. A total of four field trips were made in 1999 throughout the state covering the North-East, Flinders, Far North-East and North West pastoral districts. South Australia was experiencing an extremely dry period when field work was undertaken (Figures 49-52). For example, no observation of greater than 1,000 kg DM/ha was made during any of the four spider mapping trips. The effect of this is to limit the calibration exercise to the dry end of the seasonal conditions continuum. Hence it should be an imperative in the future to repeat, and hopefully expand, the spider mapping trips during a good rainfall and pasture growth season.

To maintain the accuracy of the data, calibrations were performed throughout each field trip on a daily basis using the techniques developed with the NSW operators. Pasture types varied across the state and modifications to the data type were changed accordingly. With the varied range of data types collected in SA, all function keys were required and modified to suit the area being traversed:

F1	Pasture Biomass, Group 1
F2	Pasture Biomass, Group 2
F3	Harvest/Transect Site
F4	Harvest Site
F5	Chenopods, Group 1
F6	Chenopods, Group 2
F7	Trees/Shrubs, Dominant 1
F8	Trees/Shrubs, Dominant 2
F9	Landsytem SA
F10	Land Condition
Shift + F1	Fire scar
Shift + F2	Comments
Shift + F3	Land Condition.

Photo standards were developed during each field trip and catalogued for reference. When encountering new vegetation communities standards were developed and Polaroid photos were taken to help in calibration. Calibration sites involved the taking of a photo and a minimum of ten half metre square quadrats clipped. These were then oven dried and weighed to determine the actual site biomass.

Approximately four pasture yield observations were made per kilometre. Figure 53 shows the distribution of pasture biomass estimates in SA.

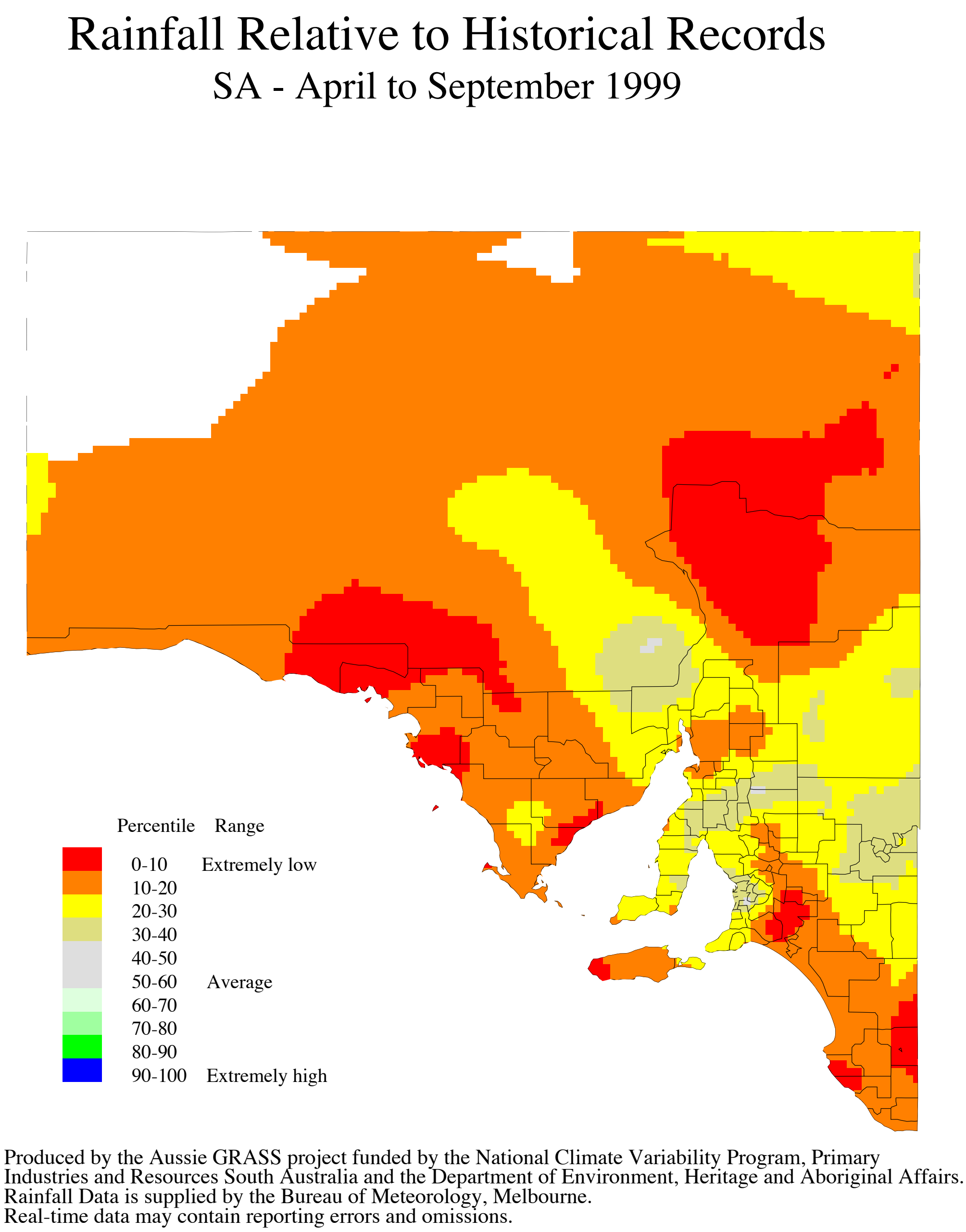
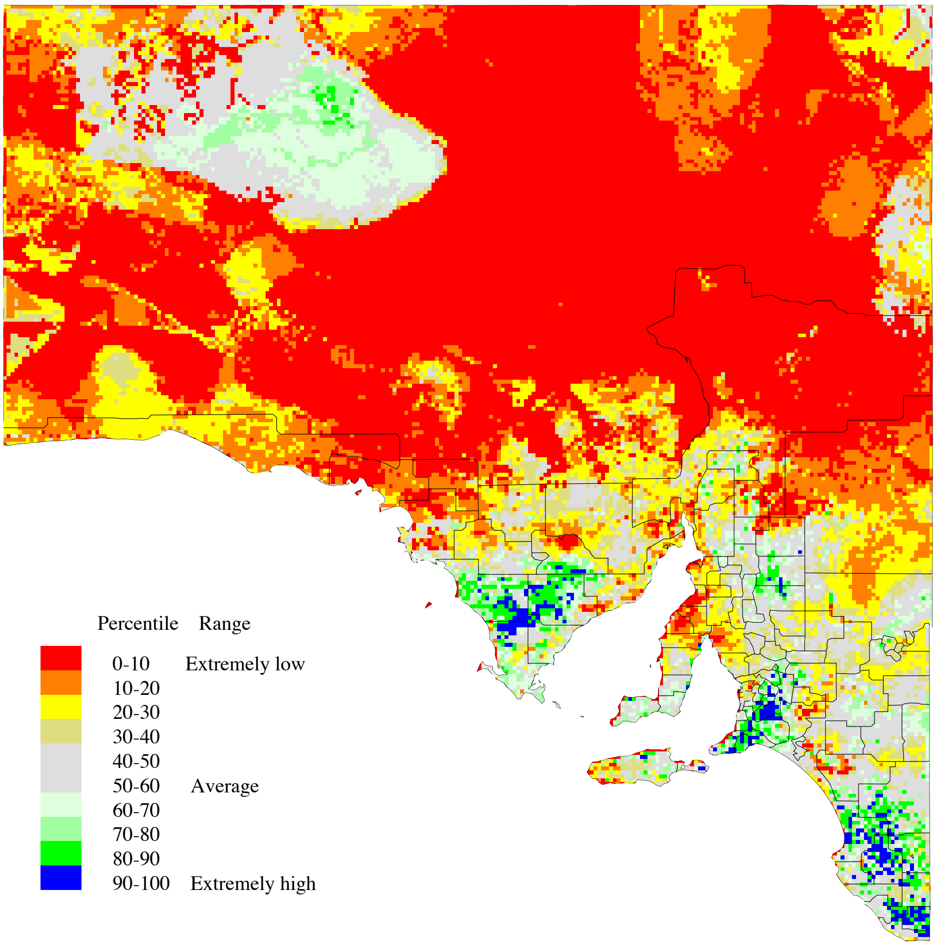


Figure 49. SA rainfall for the six months to September 1999 relative to the historical record.

Pasture Growth Relative to Last 40 Years

SA - April to September 1999

Experimental Prototype

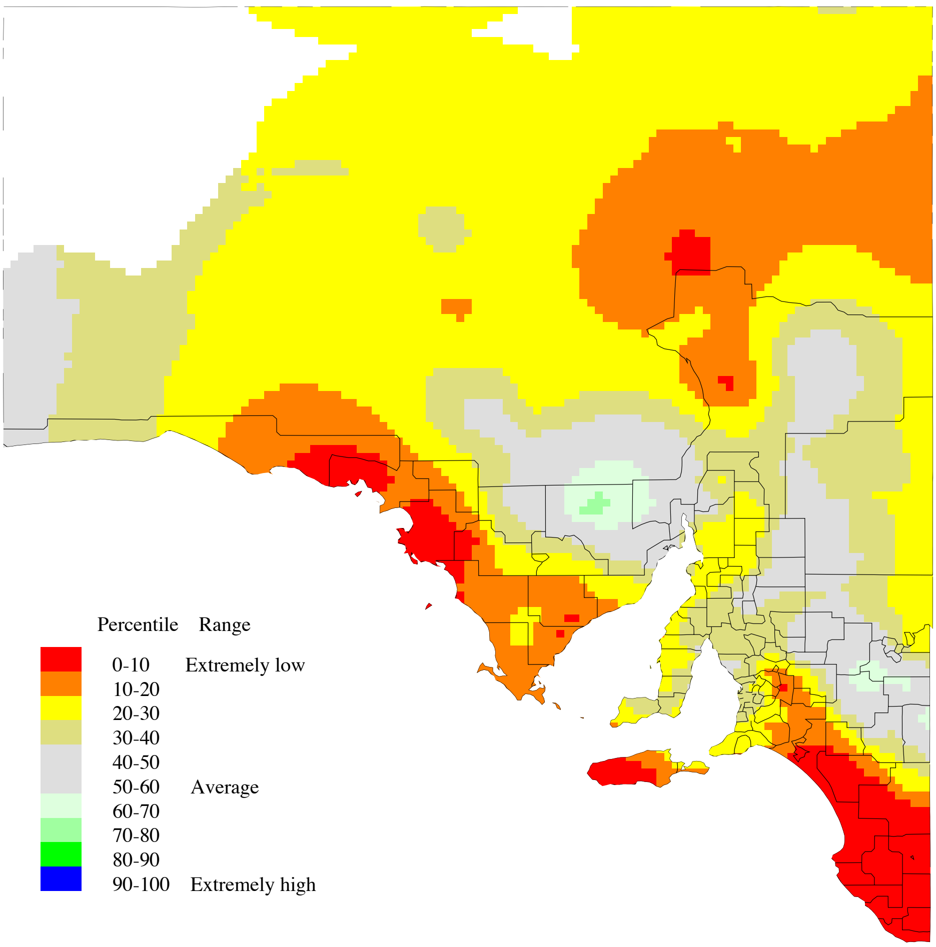


Produced by the Aussie GRASS project funded by the National Climate Variability Program, Primary Industries and Resources South Australia and the Department of Environment, Heritage and Aboriginal Affairs.

Figure 50. SA pasture growth for the six months to September 1999 relative to the historical record.

Rainfall Relative to Historical Records

SA - October 1998 to September 1999



Produced by the Aussie GRASS project funded by the National Climate Variability Program, Primary Industries and Resources South Australia and the Department of Environment, Heritage and Aboriginal Affairs.
Rainfall Data is supplied by the Bureau of Meteorology, Melbourne.
Real-time data may contain reporting errors and omissions.

Figure 51. SA rainfall for the 12 months to September 1999 relative to the historical record.

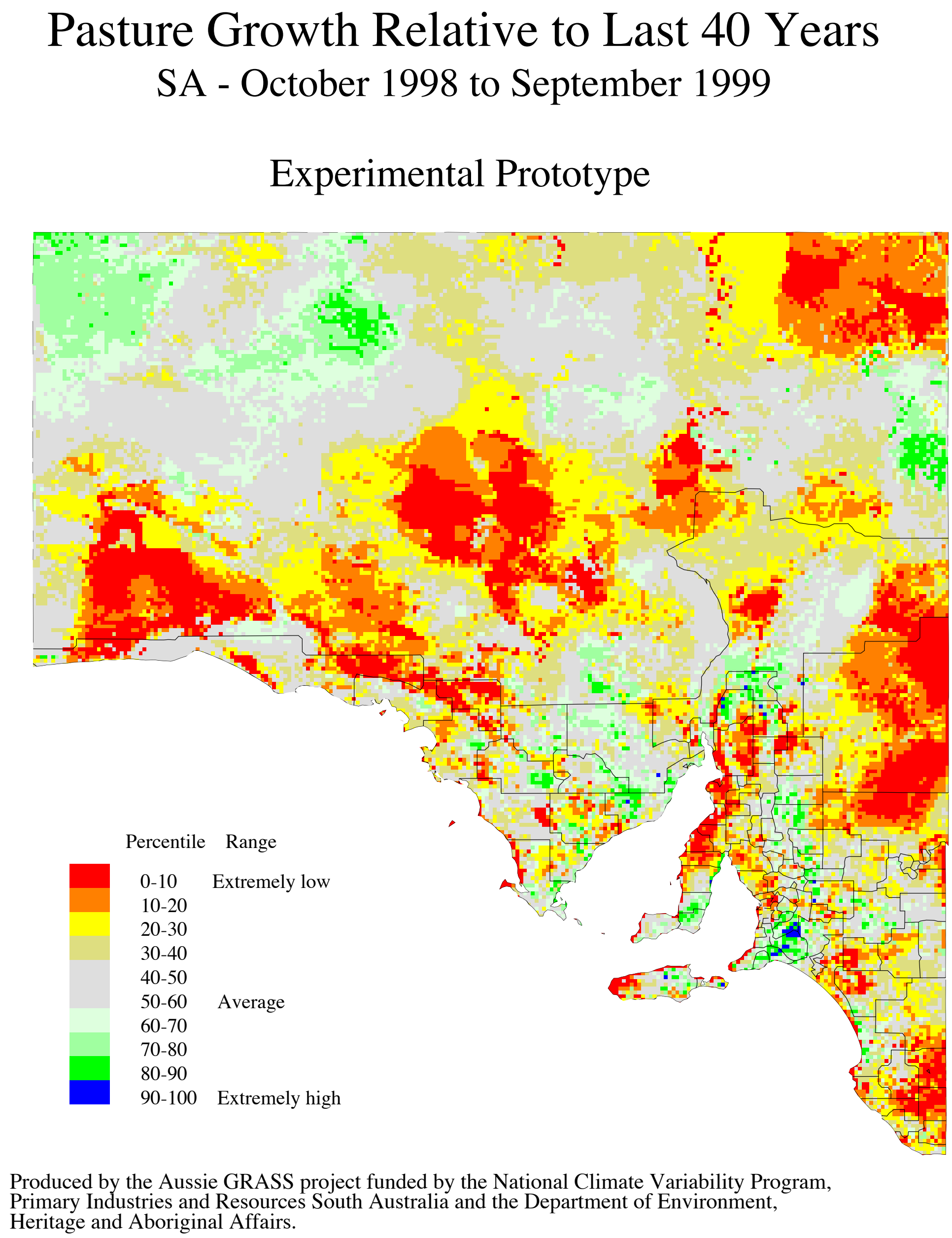


Figure 52. SA pasture growth for the 12 months to September 1999 relative to the historical record.

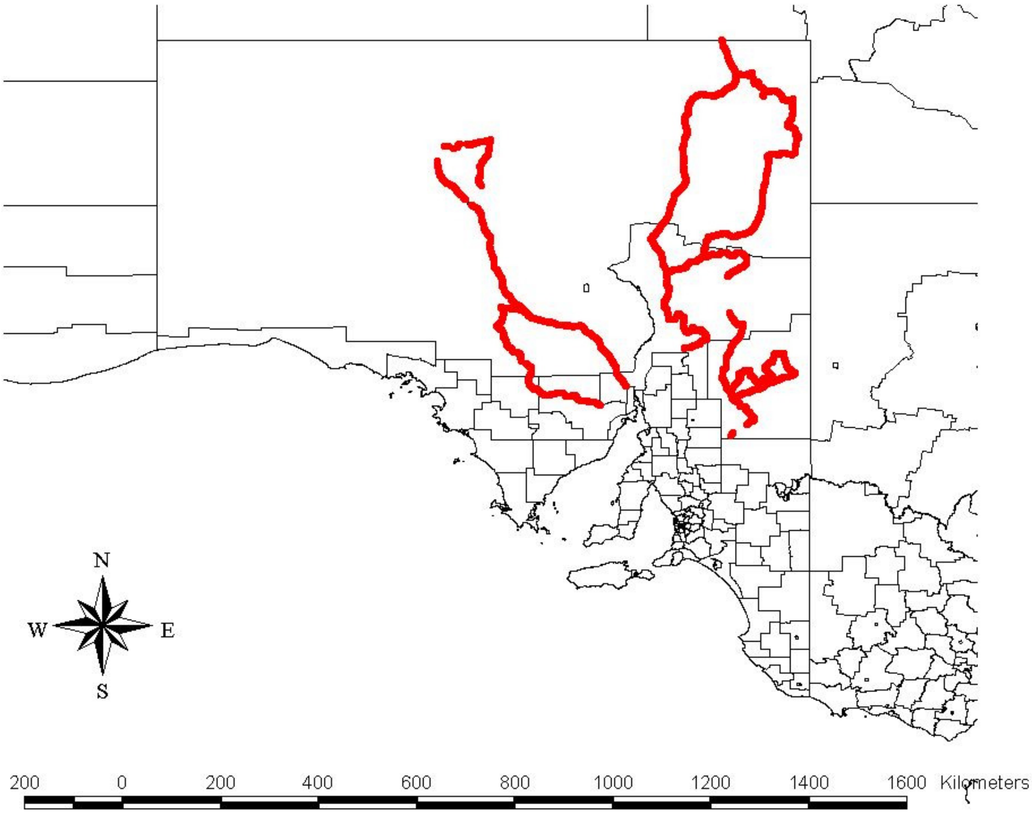


Figure 53. Location of the 17,900 spider mapping pasture biomass observations within SA. Internal boundaries are Statistical Local Areas.

6.5 Results of spider mapping

The key results of the spider mapping exercise conducted in NSW, WA and SA, in terms of pasture biomass observations, are shown in Tables 24, 25 and 26 respectively. NSW collected 19,646 useable observations over seven field trips, with only two observer periods of data rejected due to low correlation (<0.75, Hassett *et al*. 2001) with the harvest data (7-10 Sept. 1998, r^2=0.65; 16 Sept. 1998, r^2=0.24).

WA collected 22,041 useable observations over five field trips. However, six observer periods of data (6,406 observations) were rejected due to low correlation with the harvest data – the maximum correlation (r^2) rejected was 0.50. It should be noted that the arbitrary correlation value below which data were rejected was reduced to 0.62 for WA in order to maximise the number of observations available for calibration/validation of the spatial model.

SA collected 17,900 useable observations over four field trips. However, as for WA, the arbitrary threshold for data rejection was reduced to 0.62 in order to maximise the number of observations available for calibration/validation of the spatial model.

Table 24. Summary data for the NSW spider mapping.

Year	Trip No.	Where	Kms	Total obs/day	Trip date details	Accepted biomass obs/day	Total biomass obs	Date	Days/cal	r^2 RR	r^2 SC	r^2 JB	No. cal sites	Model Used
1998	1	Hay-Maude-Hay	89	311	1-4, 7-10 Sept 99	106	5019	1/09/1998	4	0.9922		0.9104	7	REM
		Hay-Maude-Balranald	212	573		187		2/09/1998						
		Balranald-Mungo-Pooncarie	292	1075		455		3/09/1998						
		Pooncarie-Oxley-Hillston	223	853		423		4/09/1998						
		Hillston-Mossgiel-Ivanhoe	225	891		515		7/09/1998	4	0.7926		**0.6464**	6	
		Ivanhoe--Menindee	300	1234		738		8/09/1998						
		Menindee-Hillston	445	1991		1379		9/09/1998						
		Hillston-Ivanhoe	396.7	1737		1217		10/09/1998						
1998	2/3	Cobar-Cobar	112	578	22 Sept, 13, 14, 16 Oct	360	2503	22/09/1998	1	0.9148		0.8932	4	REM
		Cobar-Cobar	157.3	669		494		13/10/1998	1	0.9838		0.9691	4	
		Cobar-Cobar	247	1212		801		14/10/1998	1	0.8858		0.7857	4	
		Cobar-Bourke	142	1134		848		16/10/1998	1	0.818		**0.2385**	4	
1998	4	Barnato-Wicannia-Broken Hill	324.1	1003	11, 13-16 November 98	581	3421	11/11/1998	2	0.9462	0.9742		6	REM
		Tibooburra-Cameron Cnr-'Mt Poole"	211	892		562		13/11/1998						
		Mt Poole'-Tibooburra-'Pulgumurtie'	279.6	1198		842		14/11/1998	1	0.8643	0.9948		4	
		Kayrunnera'-Mootwingee-Broken Hill	206.6	1002		690		15/11/1998	1	0.8837	0.8688		5	
		Broken Hill-Tielta-Silverton	249	1223		747		16/11/1998	1	0.9436	0.8608		4	
1998		Broken Hill-Tarawi'	238.8	1192	17-19 November 1998	740	1905	17/11/1998	2	0.9838	0.9889		4	REM
		Tarawi'-Tandou'-Menindee	265.5	1086		725		18/11/1998						
		Menindee-Broken Hill-Menindee	192	727		440		19/11/1998	1	0.9888	0.9856		6	
1999	5	Cobar-Louth	130	420	28-30 June 1999	361	1350	28/06/1999	3	0.8047	0.854		13	LINEAR
		Cobar-Barnato	106	338		308		29/06/1999						
		Cobar-Bourke-Byrock	239	766		681		30/06/1999						
1999	6	Lake Carg-Hillston-Menindee	247	516	25-27 November 1999	375	3056	25/11/1999	1	0.9779	0.8834		4	LINEAR
		Broken Hill-Menindee-Coombah	391	2225		1978		26/11/1999	2	0.781	0.7786		7	
		Broken Hill Coombah	129	785		703		27/11/1999						
1999		Coombah-Wentworth	161	444	29 Nov - 1 Dec 1999	384	2392	29/11/1999	2	0.841	0.8286		7	LINEAR
		Gol Gol-Euston-Deniliquin	310	1221		975		30/11/1999						
		Deniliquin-Goolgowi-Condobolin	426	1227		1033		1/12/1999	1	0.9606	0.9468		5	

*** (REM = Random Effects Model)** **Total = 19646**

*** RR = Rob Richards, SC = Steve Clipperton, JB = Judy Bean** **RAP biomas = 2795** NB: Observations with **bold** r^2 were rejected ie. less than 0.75 accuracy

*** Coordinate system used for all positions = UTM**

*** Datum used = Australian Geod 84**

*** Linear regression initially used for rejecting or accepting observations. All r^2 listed here are the initial linear regressions**

*** *Total obs/day* are ALL observations taken for that day. Includes chenopods, Trees/shrubs, Land condition etc.**

Table 25. Summary data for the WA spider mapping.

Year	Trip No.	Where	Trip date details	Total biomass obs	Accepted biomass obs/day	Date	Days/cal	r^2 O1	r^2 O2	No. cal sites
1999	1	Kalgoorlie	2-5 June	6425	4874	2-4 June	3	0.92	0.93	12
					1641	5 June	1	0.99	0.96	8
1999	2	Carnarvon	14-18 June	2939	1612	14-15 June	2	0.74	0.81	14
					1327	16 June	1	0.62	0.84	10
					0	17-18 June	2	0.38	0.31	15
1999	3	Meekathara	12-15 July	4931	1563	12-13 July	2	0.68	0.83	16
					3368	14-15 July	2	0.69	0.61	15
1999	4	Carnarvon	8-11 November	0	0	8-9 November	2	neg.	neg.	12
					0	10-11 November	2	0.44	0.5	21
1999	5	Meekathara	6-9 December	7746	7746	6-9 December	4	0.62	0.68	21
					Total = 22041					

*** O1 = Observer No. 1, O2 = Observer No. 2**
*** Coordinate system used for all positions = UTM**
*** Datam used = WGS84**

Table 26. Summary data for the SA spider mapping.

Year	Trip No.	Where	Trip date details	Accepted biomass obs/day	Total biomass obs	Date	Days/cal	r^2 RT	No. cal sites
1999	1	North-east SA	22-26 March	2580	2580	22-26 March	5	0.79	25
1999	2	Flinders ranges	9-10, 12-14 May	3506	1008	9-10 May	3	0.78	12
					745	12 May	1	0.64	13
					1753	13-14 May	2	0.87	11
1999	2	Far north-east SA	13-16, 20-21 August	7070	5779	13-16 August	4	0.97	24
					1291	20-21 August	2	0.63	9
1999	4	Coober Pedy	27 September - 1 October	4744	4744	27 September - 1 October	5	0.92	39
					Total = 17900				

*** RT = Roger Tynan**
*** Coordinate system used for all positions = UTM**
*** Datam used = WGS84**

7 Calibration and validation of the Aussie GRASS model

The Aussie GRASS model is a largely empirical model, representing the processes of soil water change, pasture growth, death, detachment and consumption by animals. These processes are modified by parameters, some of which remain essentially fixed for all pasture communities, and some which vary.

The current operational model is parameterised using: 1) data on pasture yield collected by field observation; and 2) greenness data (Normalised Difference Vegetation Index - NDVI) from the NOAA satellite. Field observations may include detailed soil and pasture data, and more coarse data collected using the spider mapping technique. Over 59,500 useable biomass observations were made across the southern pastures using the spider mapping technique. In NSW this coarse data was supplemented with more detailed RAP biomass observations, with 2,795 data points collected since October 1989 at 334 locations (Figure 1).

Calibration is an ongoing activity of constant model improvement which is necessary whenever additional observations become available, when model functionality changes (e.g. fires added to the model), and if input layers are changed (e.g. tree basal area or rainfall). During the calibration process, parameters were constrained to the extent that the model:

1. reproduced mean yield and greenness data (usually to within 5% of the measured values);
2. produced a reasonable replication of the time series of greenness from the NOAA satellites;
3. parameters were consistent for similar vegetation types;
4. produced plausible maps of pasture biomass and growth;
5. generally did not produce artificial boundaries in output maps; and
6. produced mean drainage division run-off to within 30% (measurement error) or better of reported values.

The spider mapping field data set was split into two groups for calibration (66.6%) and validation (33.3%). The calibration data were used to adjust parameters while the remaining data were withheld from this process and used as a check on model performance. Observations falling within a given pixel (25 km^2) on a given day were averaged to give a single pixel value. This process was done separately for ‘calibration’ and ‘validation’ observations. These pixel values then were used as the basis for the calibration and validation process.

Following evaluation of the performance statistics and acceptance of this report, it is intended to recombine the two data sets to maximise model calibration. Hence it is expected that the final calibration results will be an improvement on the calibration and validation results presented in this report.

It should be noted that, as a general rule-of-thumb, the resolution of the model and associated inputs means that the Aussie GRASS model can only be expected to approach the true mean for clusters of 30 for more pixels, or in other words, approximately ¼ of a Statistical Local Area as mapped by the Australian Bureau of Statistics.

7.1 Results

The calibration and validation results for the southern pastures using the spider mapping data are presented in Figures 54 and 55. Each of the data points in these graphs represents the mean of all calibration or validation observations, on a pixel basis, made within a specific Aussie GRASS vegetation community during the RAP - spider mapping programs. Whilst these results give an indication of the ability of the model to simulate mean biomass levels for different vegetation communities, they do not provide any information on the ability of the model to account for within season and seasonal variation within a given community. To overcome this problem it is necessary to have repeated sampling for each of the communities across a number of seasons. An alternative, cheaper approach is to plot the time series of model greenness against NOAA satellite NDVI values for each the communities. The results of this form of calibration are shown in Figure 56 for all communities within the southern pastures in terms of mean NDVI values, and in Figures 57-63 as a time series for selected communities.

The two most readily identifiable features of the calibration-validation process were: 1) the relatively small number of data points and the number of vegetation communities for which data were collected in the southern pastures of WA; and 2) the extremely low biomass yields recorded in SA during the spider mapping program in SA. Both these factors have limited the calibration process.

7.2 Calibration issues

Despite the use of the constraints described above during the calibration process, it is still possible to obtain non-unique solutions in parameter space. Major issues identified as a result of this and earlier calibration exercises were:

- Calibration without direct measurements of growth, water use by plant communities, and nitrogen uptake limits the ability to constrain parameters in parameter space. Hence the availability of the SWIFTSYND data for communities in the VRD proved very useful in those and related areas.
- Errors in the tree density map where basal area was over or underestimated by one or two units (m^2/ha). These errors are most noticeable in coastal and sub-coastal where tree density was underestimated. Data collected in the Southern Pastures area of NSW on % canopy cover, basal area and foliage projected cover of trees and shrubs has not yet been applied to validate the tree density map in this area.
- Noise in the NDVI signal related to sun angle and bi-directional reflectance (largely associated with tree canopy illumination and shadow), cloud contamination etc.
- Large and poorly mapped plant communities (notable in Western Australia)
- Fire scars maps were not available pre-1999 to reset biomass and NDVI.

Future near-term developments are planned to include the following:

- Automatic calibration - it should be possible to use advanced mathematical tools to automatically calibrate model parameters. These techniques have been used on older ‘test’ versions of a Queensland only spatial model, and on point models. However the complexity of running these tools effectively in a supercomputing environment has slowed development of this capability.
- Improved correction of noise in the NDVI calibration data.
- Incorporation of better tree mapping data from Landsat TM analyses.

8 Additional spatial input data

NSW contributed a number of additional data sets to the national modelling framework:

- Soils data – a more detailed data set was provided for model parameterisation on soils for the south western area of NSW. This data included attributes needed such as bulk density and water holding capacities.

- Kangaroo/goat survey numbers – Data from NSW National Parks and Wildlife Service aerial counts of kangaroos and goats was provided for model input. Data provided included the southern pastures area for the years 1996 to 1998.

In addition, NSW worked with BoM to increase by 18 the number of volunteers reporting rainfall via BoM’s telegraphic network in western NSW. This was done by first identifying gaps or low density areas in the network of rainfall reporting stations (either postal or telegraphic). Properties in these areas were located and listed as potential contributors. Owners/managers of these properties were initially contacted by phone. Those willing to operate as new telegraphic stations were then sent a letter of explanation with an enclosed agreement form. The Regional Director of BoM in Sydney responded almost immediately to the request and the necessary equipment was installed at the 18 new sites.

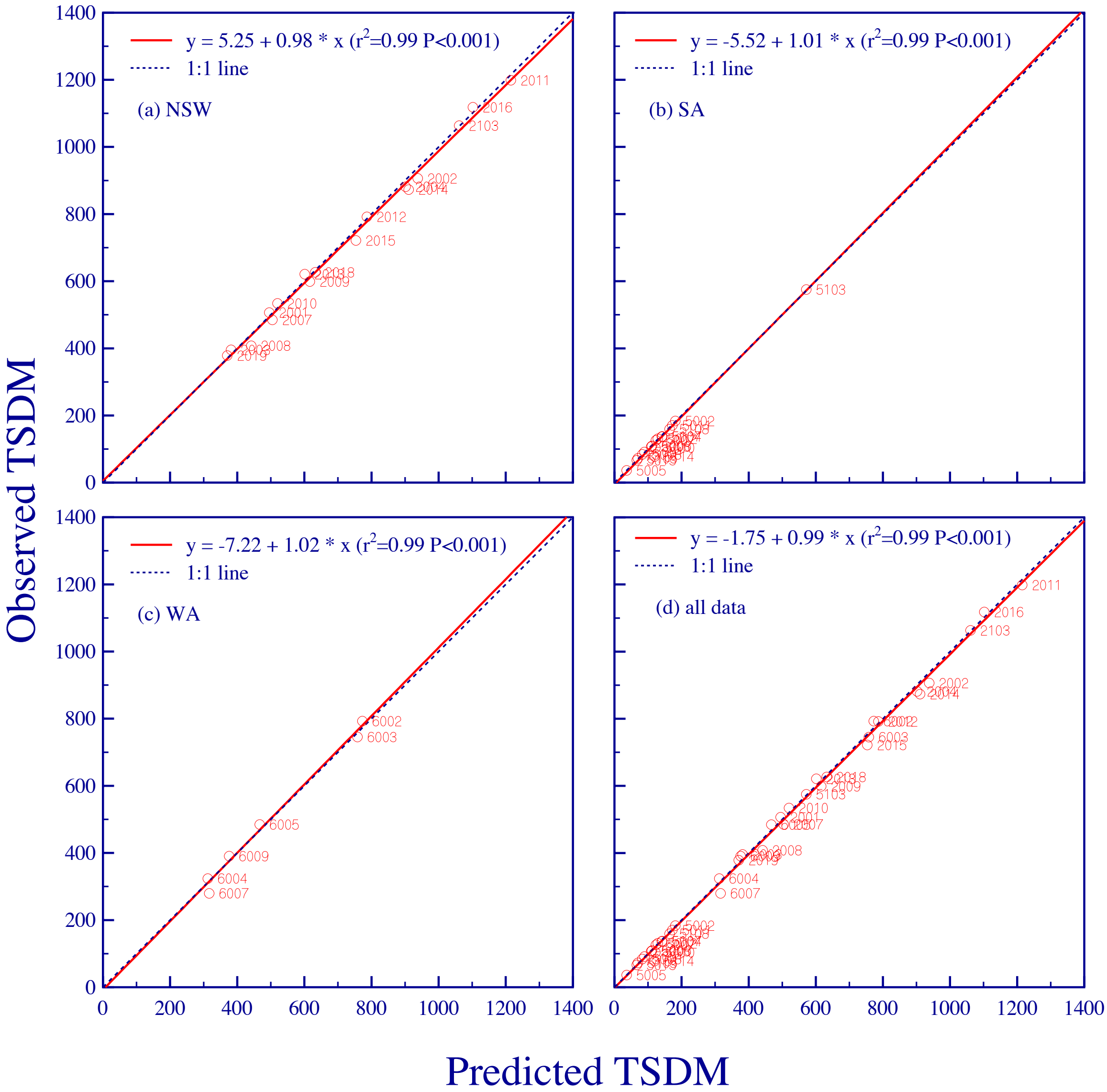


Figure 54. Observed and predicted TSDM values for southern pasture's vegetation communities in NSW (a), SA (b), WA (c), and combined (d) following calibration. The observed values for each community represent the mean of all calibration observations, on a pixel basis, for that community collected as part of the RAP - spider mapping programs. The predicted value for each vegetation community is the mean of all values for the same pixels and on the same dates as the observations were made. The labels for each of the data points are the vegetation codes for each of the communities as used within the Aussie GRASS model.

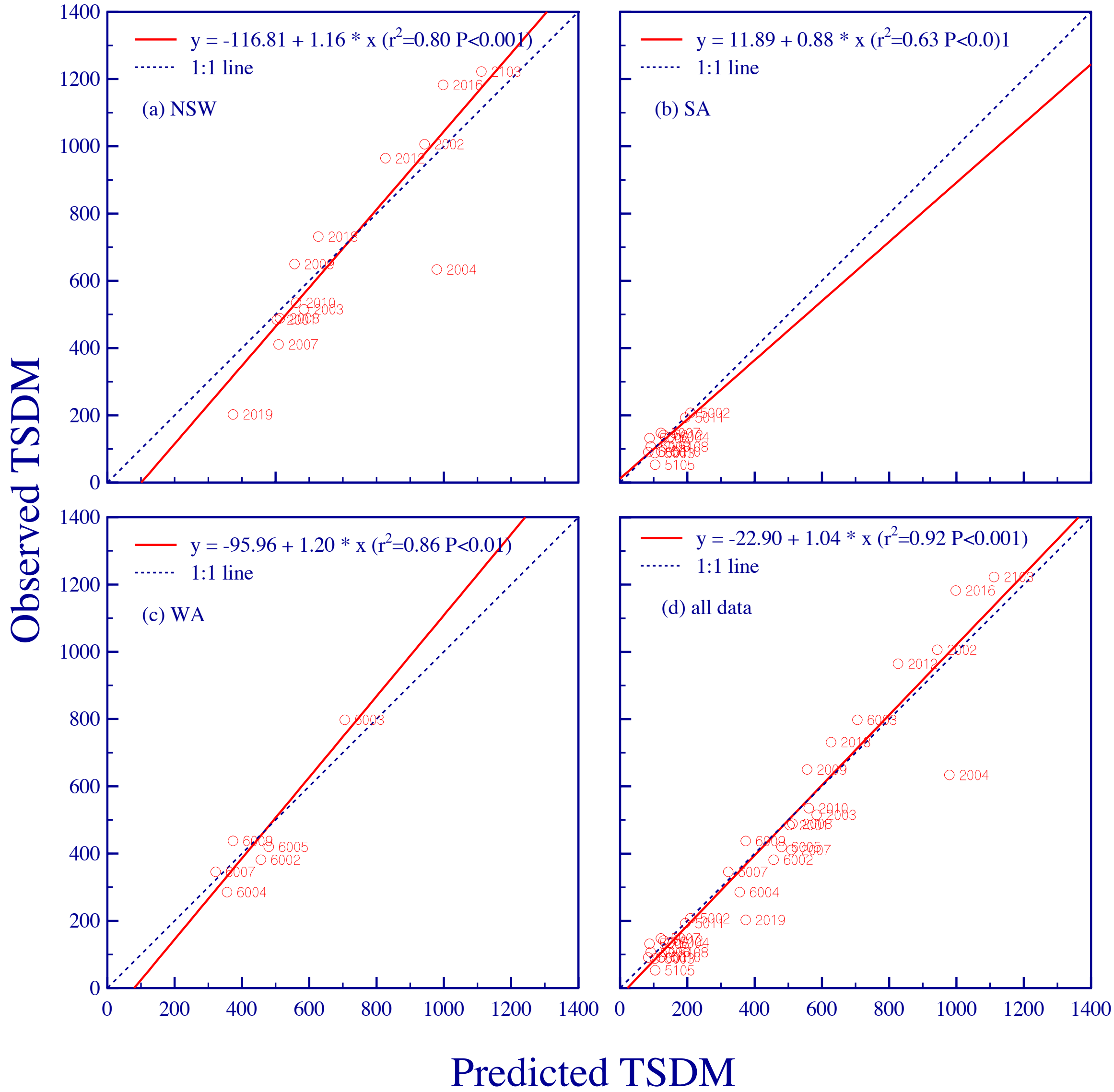


Figure 55. Observed and predicted TSDM values for southern pasture's vegetation communities in NSW (a), SA (b), WA (c), and combined (d) following validation. The observed values for each community represent the mean of all calibration observations, on a pixel basis, for that community collected as part of the RAP - spider mapping programs. The predicted value for each vegetation community is the mean of all values for the same pixels and on the same dates as the observations were made. The labels for each of the data points are the vegetation codes for each of the communities as used within the Aussie GRASS model.

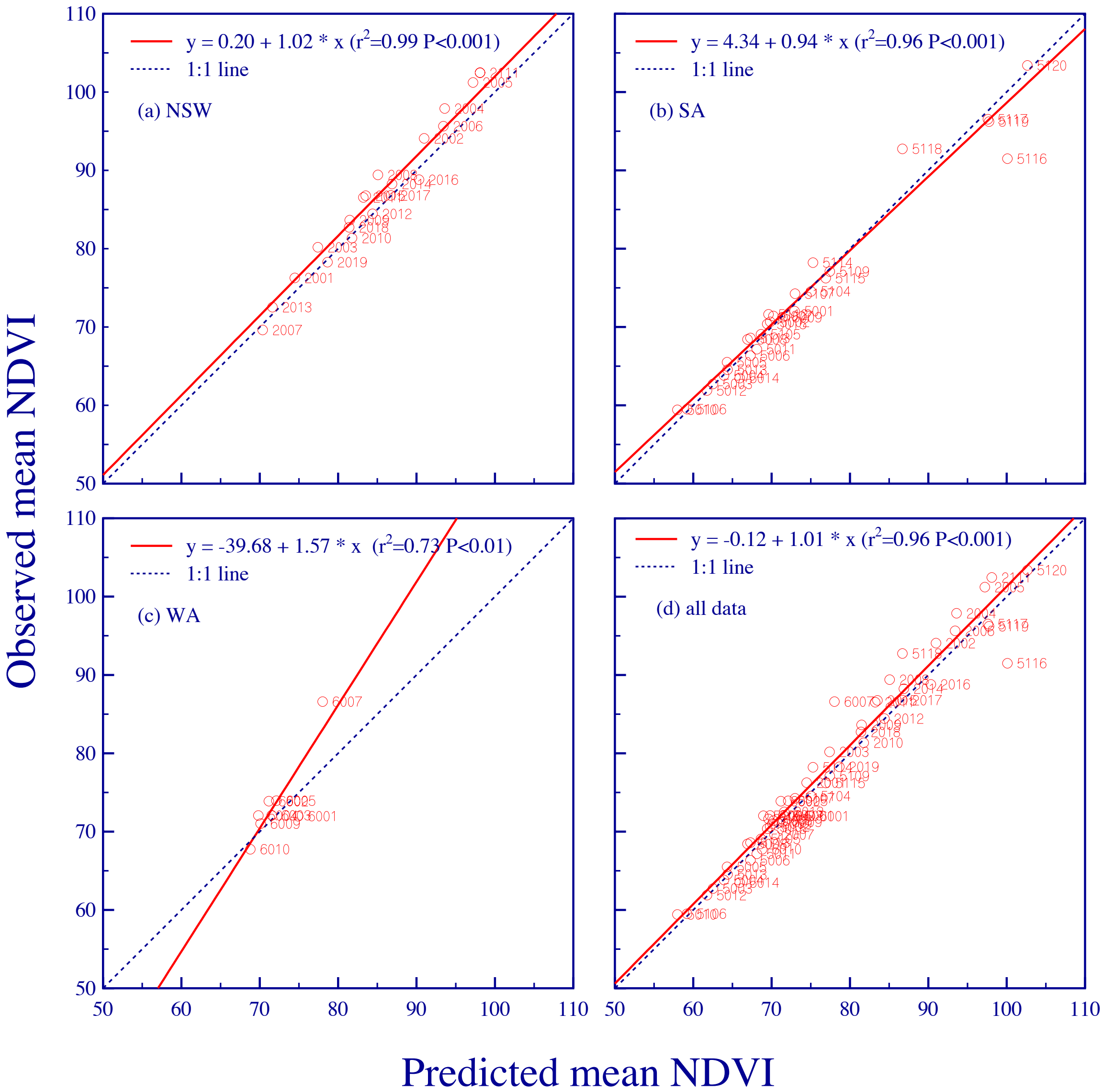


Figure 56. Observed and predicted mean NDVI values for southern pasture's vegetation communities in NSW (a), SA (b), WA (c), and combined (d) for the period 1982-1992 following calibration.

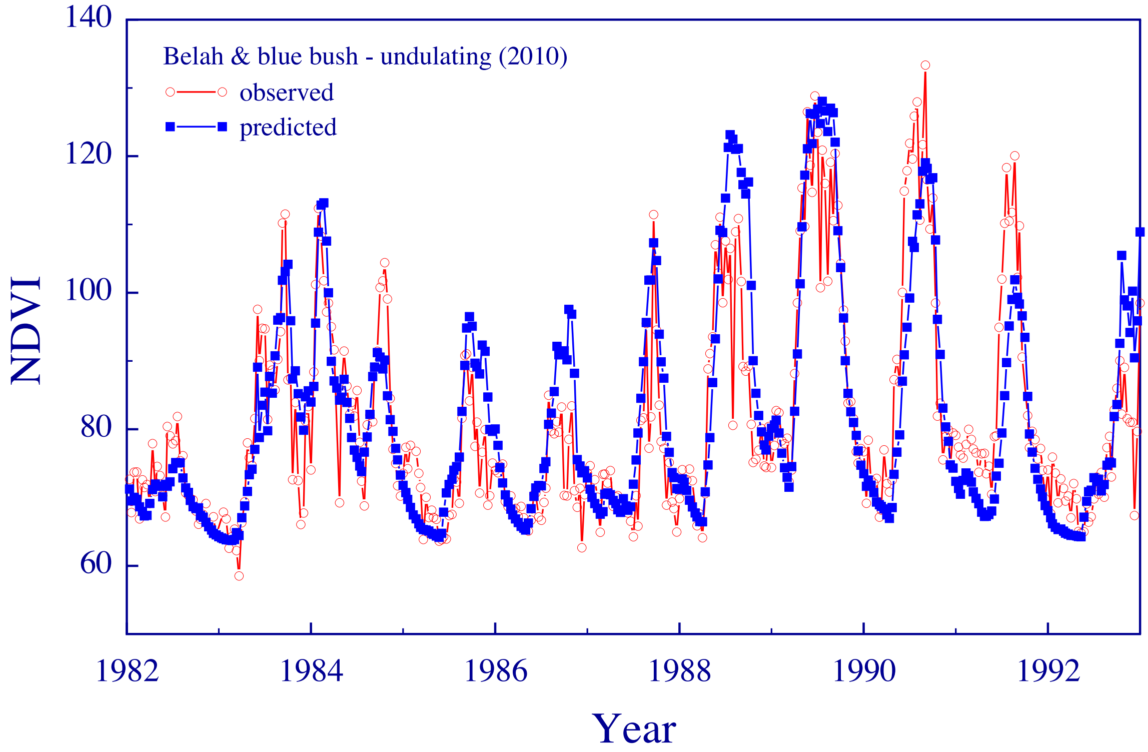


Figure 57. Time series of observed and predicted NDVI values for the belah and bluebush community (2010) of NSW.

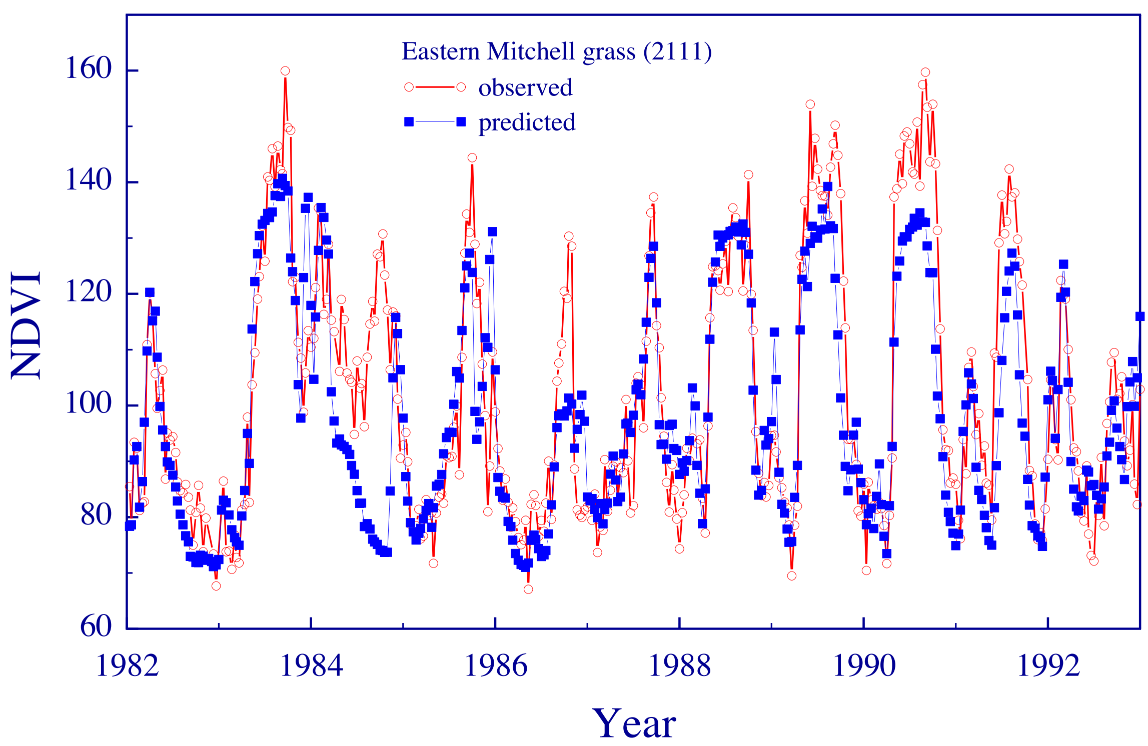


Figure 58. Time series of observed and predicted NDVI values for the eastern Mitchell grass community (2111) of NSW.

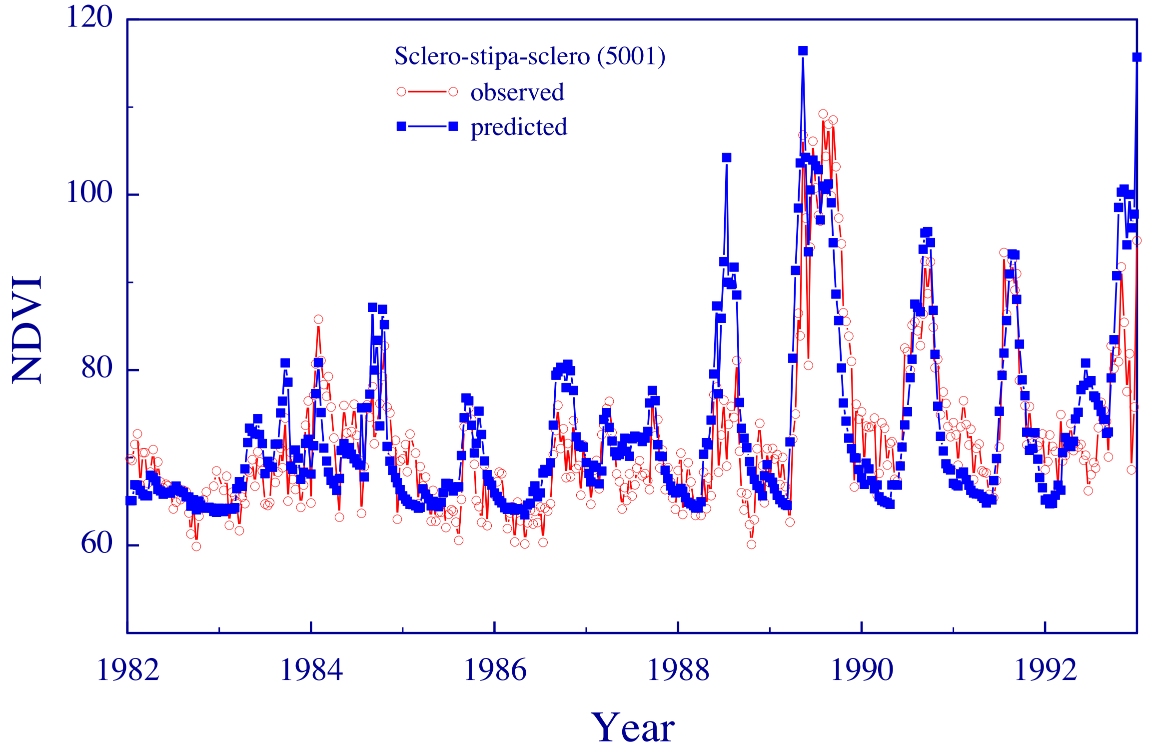


Figure 59. Time series of observed and predicted NDVI values for the 'sclero-stipa-sclero' community (5001) of SA.

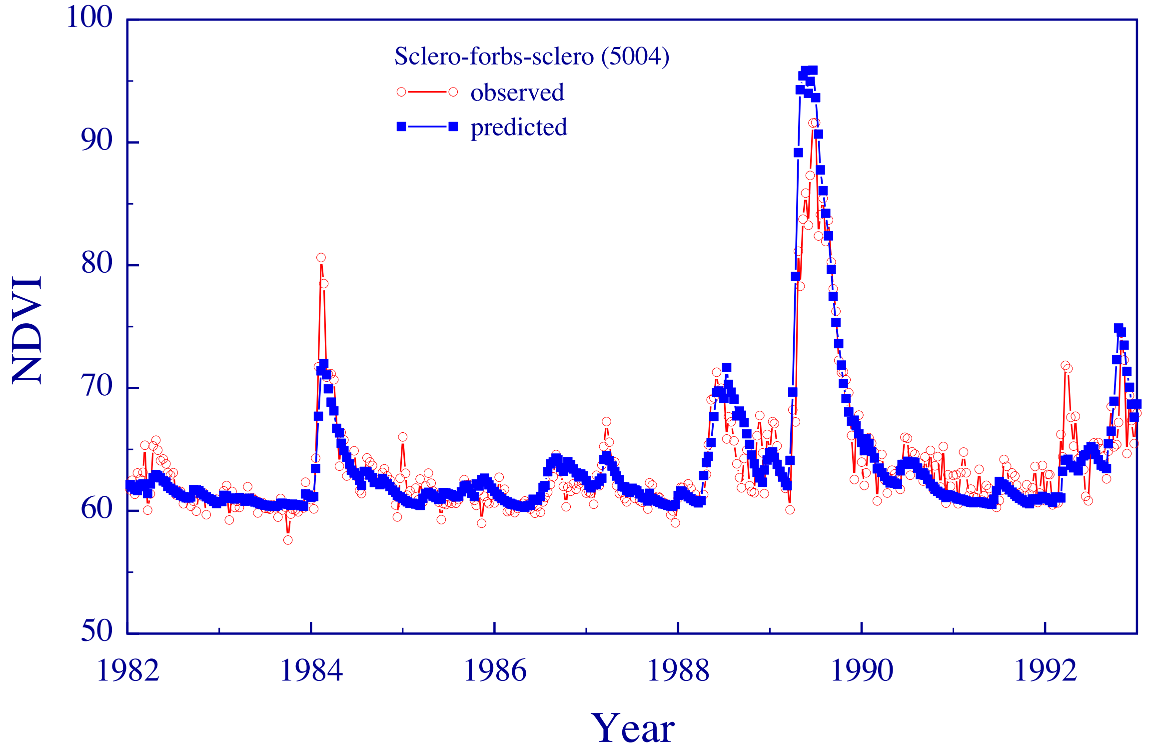


Figure 60. Time series of observed and predicted NDVI values for the 'sclero-forbs-sclero' community (5004) of SA.

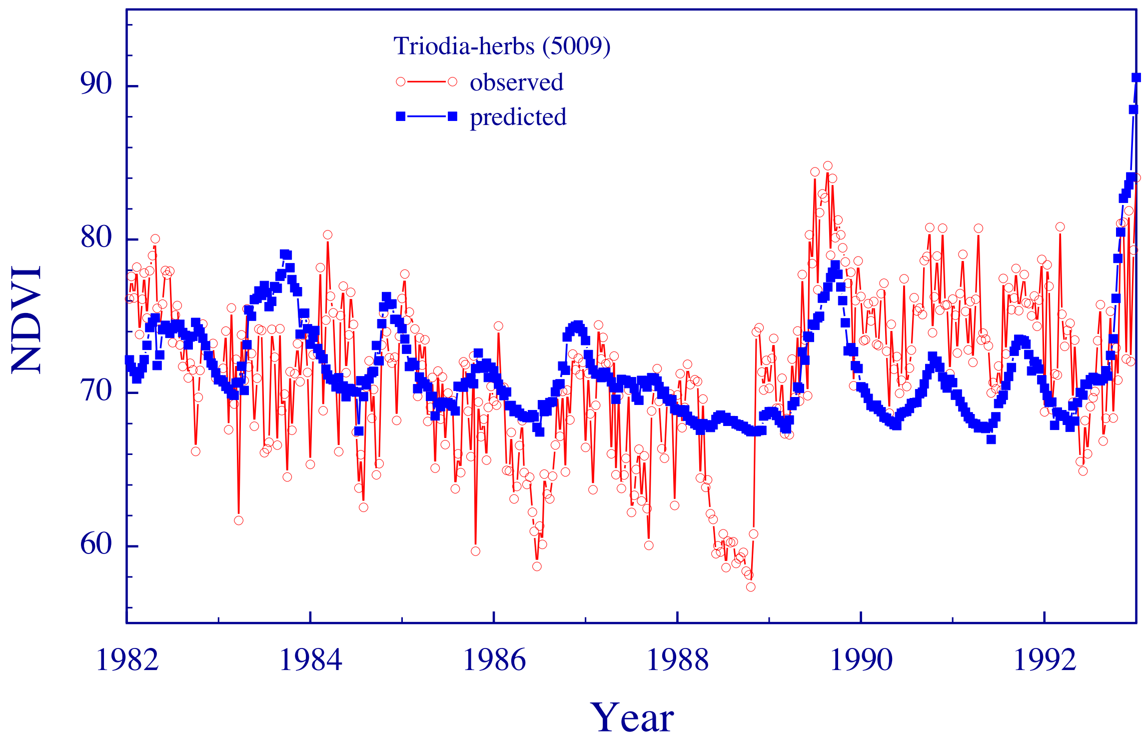


Figure 61. Time series of observed and predicted NDVI values for the 'triodia-herbs' community (5009) of SA.

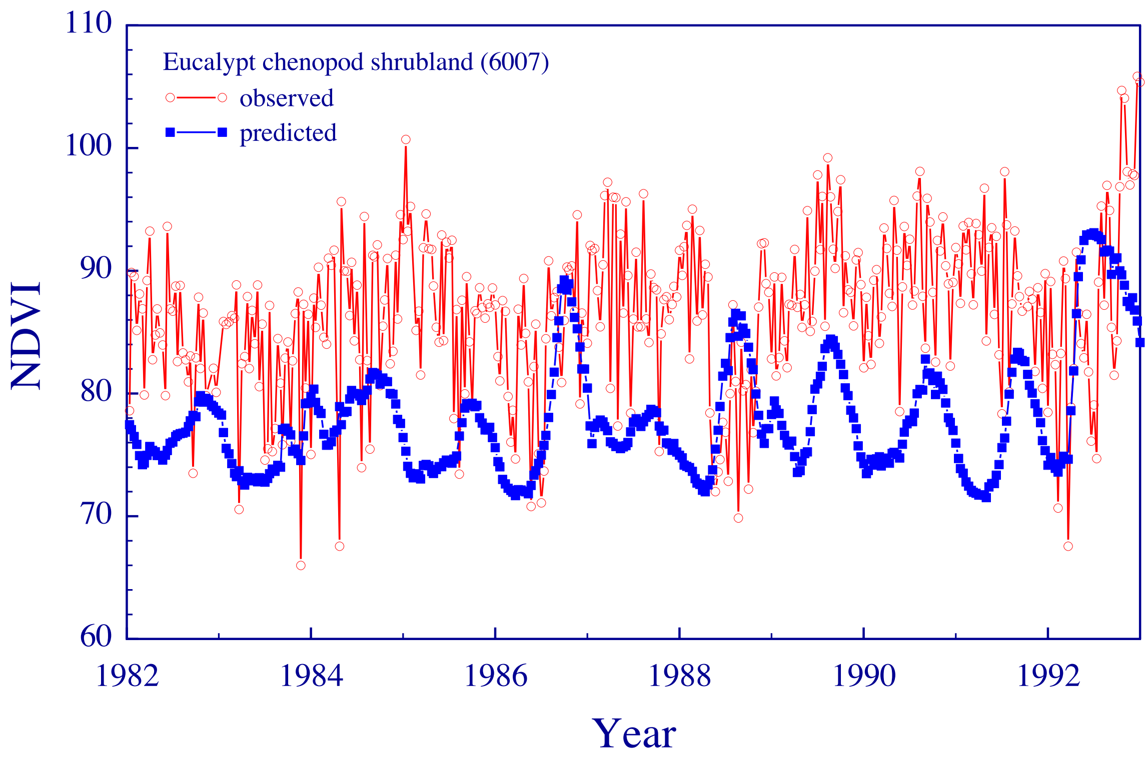


Figure 62. Time series of observed and predicted NDVI values for the eucalypt-chenopod shrubland community (6007) of WA.

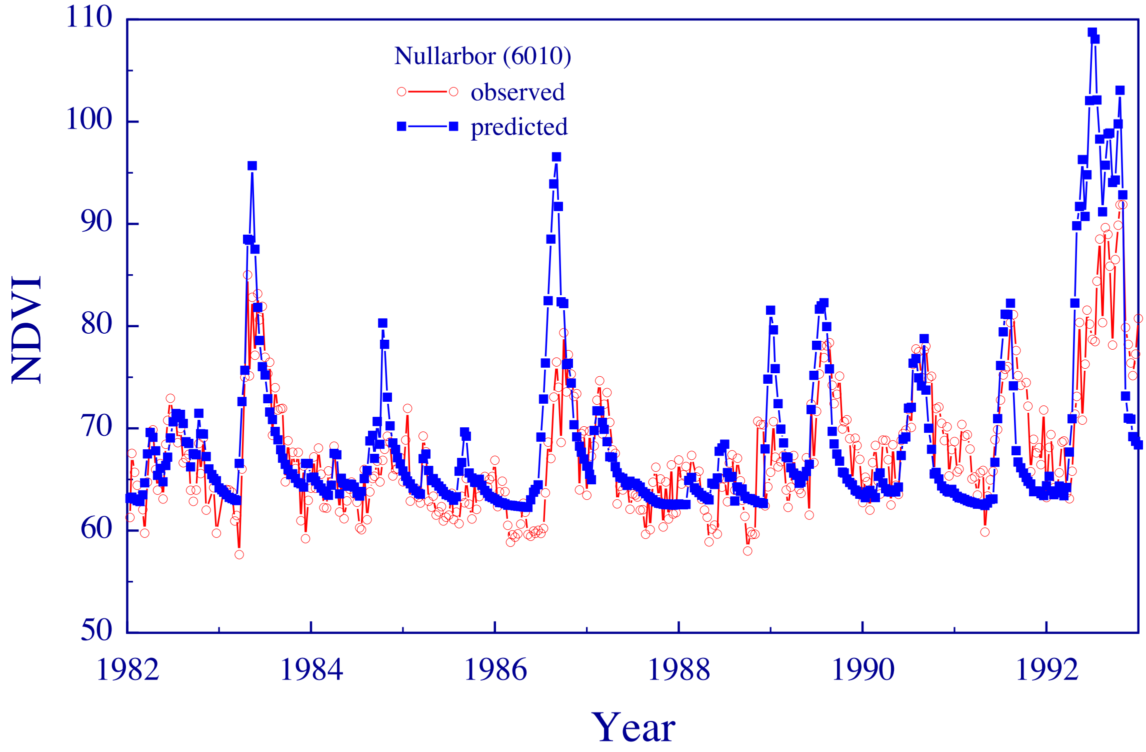


Figure 63. Time series of observed and predicted NDVI values for the Nullarbor community (6010) of WA.

9 Discussion

The value of accurate and timely information on seasonal conditions, particularly when placed in the context of its relativity to historical records, cannot be underestimated. For government agencies concerned with the sustainable use of natural resources this information can be used to provide a focus on areas that are identified as being potentially at risk of degradation. Extension and research resources can therefore be directed to these areas. Similarly the ability to place the current season in the historical context provides essential information for the determination of exceptional circumstances declarations.

The Southern Pastures sub-project provided an opportunity for the collaborating States to refine information products from the Aussie GRASS spatial pasture production model through a process of model parameterisation and validation. The use of relevant State historical data sets and field data collection was an essential component of this. There is little information available on growth rates of perennial chenopods that are of such pastoral and ecological significance in western NSW. More research such as the establishment of 'SWIFTSYND' type sites would be beneficial for further model parameterisation. Similarly, field data capture is expensive but valuable in model calibration/validation.

While other pasture production models are available for use, they are specific in design and lack spatial applicability. The GRASP model proved to have robust spatial applicability despite those problems outlined in the model evaluation section. There is potential for further development of the Aussie GRASS model to include important processes such as dynamic shrub competition, use of a browse component, and the use of several plant guilds.

Both NSW agencies involved in the Aussie GRASS project believe that it has been of benefit to them and intend to contribute funds and resources to the ongoing maintenance and development of the Aussie GRASS model for the next two years.

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