5.0 A QUANTITATIVE APPROACH TO ESTIMATING "SAFE" GRAZING CAPACITIES

5.1 Introduction

Determining the grazing capacity of grazing lands, and understanding the consequences, is one of the most difficult tasks in grazing management (Vallentine 1990a). A "safe" grazing capacity is defined here as the number of dry sheep equivalents that can be carried on a land system, paddock or property in the long-term (20-30 years) without any decrease in pasture condition and without accelerated soil erosion (after Scanlan *et al.* 1994). In this thesis it differs from a “safe” ‘stocking rate’ which is a tactical or shorter term (seasonal or annual) calculation of “safe” stock numbers.

Several approaches are available for determining grazing capacity and appropriate stocking rates. Most are based on experience of "average" properties in "average" years (Wilson *et al.* 1990), and trial and error, coupled with regular adjustments. Due to the variability in climate and land types in south-west Queensland, the use of district averages is unlikely to yield appropriate grazing capacities for individual properties. Despite this, decisions on grazing capacities must be made and Vallentine (1990a) lists seven methods for this. Briefly these were:

1. Initial stocking rate tables for various land and pasture types such as those reported for south-west Queensland by Mills and Purdie (1990);

2. Known or historical stocking rates adjusted for land condition and trend information. This is comparable to Condon *et al.* (1969) where known grazing capacity was corrected for factors such as precipitation, soil fertility, plant community type and topography;

3. Estimates of standing forage yield and conversion to stock numbers using appropriate levels of use for that forage;

4. Percentage utilisation methods where actual estimates of forage utilisation are compared with appropriate levels of use for that forage;

5. Forage comparison methods in which the grazing land under question is compared to a mental ideal or standard for that forage;

6. Energy based methods requiring detailed measurements matching the energy content of forages to the requirements of grazing animals; and

7. Forage density methods requiring laborious estimates of forage density and quality to develop indices for appropriate stocking rates.

A number of these approaches requires subjective judgment and some prior level of experience regarding the forages in question. To remove this limitation, a quantitative approach to estimating grazing capacity linking ecological principles with local knowledge and experience was examined.

This chapter describes the development of such an approach building on the primary productivity and simulation results from Chapters 3 and 4. It is equivalent to the third method listed above by Vallentine (1990a) except it is based on calculated annual forage growth rather than standing forage yield.

In this Chapter, selected results are presented in the materials and methods section as they were integral to further development of the method for estimating grazing capacities.

5.2 Model development

A quantified approach to estimating “safe” long-term grazing capacities was developed based on primary productivity and simulation studies described in Chapters 3 and 4. The method is comparable to that developed by Scanlan *et al.* (1994) for resource units and properties in northern Australia. In place of the resource units of Scanlan *et al.* (1994), land systems (Mills and Lee 1990) were chosen in this study as the base unit for estimating the amount of forage grown, the "safe" level of use of that forage and the grazing capacity. Land systems have been defined by Christian and Stewart (1968) as 'an area or group of areas throughout which there is a recurring pattern of topography, soils and vegetation'. These have been mapped for south-west Queensland by Dawson (1974) and Mills and Lee (1990). Using this mapping, land systems can be readily identified and mapped at the paddock and property scale.

A "safe" grazing capacity is defined here as the number of dry sheep equivalents (DSE) that can be carried on a land system, paddock or property in the long-term without any decrease in pasture condition and without accelerated soil erosion (after Scanlan *et al.* 1994).

Mathematically a "safe" grazing capacity can be represented as:

"safe" grazing capacity(DSE/land system) = (**amount of forage which can be safely eaten** (kg/ha/year) / **amount eaten per dry sheep** (kg/DSE/year)) * **area of the land system** (ha)

where:

amount of forage which can be safely eaten (kg/ha/year) = (**"safe" level of forage utilisation** (%) / 100) * **average annual forage grown** (kg/ha/year)

The above relationship differs from other concepts of forage utilisation (e.g. Beale *et al.* (1986), Orr *et al.* (1993), Anderson *et al.* (1994)). These authors expressed utilisation as a proportion of standing dry matter either measured or observed in the field at some point in time. Standing dry matter measured or observed in the field may include dry matter carried over from the previous 12 months and is thus distinct from average annual forage grown. The latter is difficult to measure but can be estimated using primary productivity studies linked with computer simulation. Estimates of average annual forage grown and utilisation of this material over a 12 month period (May to April) are used in this chapter. These estimates do not include carry-over material.

Thus the four factors which need to be determined were:

- land system areas of a property (ha);
- amount eaten (intake) per dry sheep (kg/DSE/year);
- average forage grown (kg/ha/year) for each land system and property; and
- "safe" level of forage utilisation (%) for each land system.

5.2.1 Land system area

The land system area was estimated by overlaying 1:250,000 scale cadastral maps with 1:250,000 scale land system maps and measuring land system area per property with a planimeter.

5.2.2 Intake

While daily intake varies with the type and quantity of pasture and the type and physiological age of an animal, an average annual amount of forage eaten (intake) was assumed to be 400 kg/DSE/year (McMeniman *et al.* 1986). While a dynamic intake model relating intake to the quantity of forage available would be applicable for estimating short term stocking decisions an average annual intake was chosen to match the calculation of average annual forage grown. The intake of leaf from the mulga tree (*Acacia aneura*) is also considered in this study and its estimation is described later in Section 5.2.3.4.

The remaining two factors, average annual forage grown and "safe" level of utilisation of this forage, are more difficult to estimate. Thus the key to calculating "safe" grazing capacities for land systems and properties in south-west Queensland was to develop a methodology for determining average annual forage grown and a "safe" level of utilisation of this forage.

5.2.3 Forage grown

Individual grazing properties in south-west Queensland have a unique mix of land systems and occur across a range of climate (rainfall and vapour pressure deficit, Chapter 1). To examine the grazing capacities of these properties required an estimate of average annual forage grown for each of the land systems found on a property. As long-term primary productivity data for many of these land systems were not available, a method for estimating average annual forage growth for any land system in south-west Queensland was required.

In Chapter 4 the forage production model GRASP was successfully calibrated to 9 sites representing 8 land systems. This enabled the examination of long-term forage growth on these sites. Without calibration data and climatic records for the remaining 172 land systems it would be difficult to use the GRASP model to estimate growth on these land systems.

An alternative was to explore a rainfall use efficiency (RUE) (kg/ha/mm) approach and apply it to individual land systems on individual properties. This approach assumes a linear relationship between forage growth (FG) and rainfall (RAIN) (e.g. Le Houerou and Hoste (1977), and Milchunas *et al.* 1994).

The method attempted to account for:

- the variation in productivity between land systems;
- the temporal and spatial variation in the vapour pressure deficit (VPD); and
- the impact of trees and shrubs (spatial but not temporal).

Average annual forage grown (FG) for a land system was calculated as the product of potential forage grown (PFG), an index describing the impact of woody species (WI) and an empirically derived multiplier accounting for the spatial distribution of woody species (Section 5.2.3.3.1):

$$\mathbf{FG\ (kg) = PFG\ (kg) * WI * 1.168}$$

where the potential forage grown (PFG) for a land system was the product of the standard rainfall use efficiency for the land system (SRUE), a vapour pressure deficit index (VPDI), long-term average annual rainfall (RAIN) and the area (AREA) of the land system:

$$\mathbf{PFG\ (kg) = SRUE\ (kg/ha/mm) * VPDI * RAIN\ (mm) * AREA\ (ha)}$$

5.2.3.1 Estimation of standard rainfall use efficiencies for land systems

To apply a rainfall use efficiency to any land system at any location in the study region, a method for predicting rainfall use efficiencies using site data was established as follows.

For each of the 8 land systems (9 sites) analysed in Chapters 3 and 4 a standard rainfall use efficiency (SRUE) at Charleville (146^{o}15' east and 26^{o}24' south) was estimated using the regressions from Table 4.8. This point was chosen as a standard reference, as the simulations conducted in Chapter 4 used daily climatic data from Charleville. The objective was to remove spatial variability in rainfall allowing examination of the relationship between standard rainfall use efficiencies and site data. In addition, the regressions in Table 4.8 did not account for the spatial variability in the vapour pressure deficit as climatic data from only one location (Charleville) was used in the simulation studies of Chapter 4.

Site data describing chemical and physical soil properties (Bulk 0-10cm) from the Western Arid Region Land Use Studies (WARLUS) (Dawson and Ahern 1974, Turner and Ahern 1978, Mills and Ahern 1980 and Ahern and Mills 1990) were used (Table 5.1) in a best subset multiple regression to examine the relationships between site data and standard rainfall use efficiencies. These site data were used as they were available for 78% of the land systems in south-west Queensland. For the nine sites examined standard rainfall use efficiency was best correlated to a combination of soil pH, total phosphorus (TotP) and the fine sand fraction (FS).

To estimate a standard rainfall use efficiency for each land system in south-west Queensland (Table 5.2 and summarised in Table 5.3) this regression was applied to the site data representative of each land system:

$$\textbf{SRUE (kg/ha/mm) = 0.2970 * pH + 22.1169 * TotP(\%) - 0.0149 * FS(\%)} \quad (R^2=0.93 \;\; n=9)$$

While the range of data representing the nine sites did not cover the diversity reported in the WARLUS site descriptions (Table 5.1) the resultant range of calculated SRUE (1.3 - 5.6 kg/ha/mm) (Table 5.2) was comparable to the range reported in Chapter 3 (1.28 - 3.00 kg/ha/mm) and by Le Houerou (1984) (0.5 - 10 kg/ha/mm) in Chapter 4.

Table 5.1 Site data from the Western Arid Region Land Use Studies (WARLUS) Parts I-IV (Dawson and Ahern 1974, Turner and Ahern 1978, Mills and Ahern 1980 and Ahern and Mills 1990) for comparison with rainfall use efficiencies standardised to Charleville's location and climate (SRUE (kg/ha/mm)). Maximum and minimum values across WARLUS shown.

SRUE *	pH	Organic Carbon (%)	Tot. N (%)	Tot. P (%)	Coarse Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)	Soil Water at -33 kPa (%)	Soil Water at -1500 kPa (%)	Avail. Soil Water (%)
3.37	8.1	0.80	0.08	0.058	3	24	16	57	38	20	17
1.53	5.2	0.78	0.05	0.023	51	30	5	14	8	4	4
2.42	8.3	0.46	0.05	0.038	20	30	5	45	31	18	13
3.39	5.8	0.50	0.04	0.068	38	34	7	23	10	6	5
1.68	5.6	0.81	0.05	0.033	23	47	11	19	12	6	6
1.36	6.1	0.55	0.05	0.059	28	49	7	20	11	4	7
2.29	5.1	0.63	0.06	0.049	15	51	8	28	17	8	9
1.86	5.1	0.63	0.06	0.049	15	51	8	28	17	8	9
2.24	5.9	0.54	0.03	0.013	59	29	4	9	5	3	2
Max	9.2	2.0	0.10	0.170	73	69	25	66	39	27	24
Min	4.2	0.1	0.01	0.009	1	14	0	3	2	1	1

Table 5.2 Calculated standard rainfall use efficiencies (SRUE kg/ha/mm) for the WARLUS land systems of Dawson and Ahern 1974 (Part I), Turner and Ahern 1978 (Part II), Mills and Ahern 1980 (Part IV) and Ahern and Mills 1990 (Part III).

Land Zone	Land System	Part 1	Part 2	Part 3	Part 4	Land Zone	Land System	Part 1	Part 2	Part 3	Part 4
Alluvial Plains Open	A1	1.9	2.5	2.4	2.5	Hard Mulga Lands	H1	2.1	*	1.8	2.3
	A2	*	2.4	*			H2	1.8	1.9	1.6	
	A3	2.0	2.5	2.1			H3	2.2	*	1.7	
	A4	2.5	1.8				H4	1.3	1.6	1.4	
	A5	*	2.1				H5	1.6	1.6		
	A6	2.1	2.4			Claypans / Lakes	L1	2.3	*	2.4	*
Undulating Brigalow Lands	B1				*		L2	2.5		*	*
	B2				2.8	Soft Mulga Lands	M1	2.0	2.2	1.7	1.9
	B3				2.6		M2	1.9	1.8	1.7	*
	B4				2.9		M3	*	1.6	1.7	
	B5				5.6		M4	*	*	1.7	
Channel Country	C1	2.8	2.3				M5	2.1		1.8	
	C2	2.4	2.5			Spinifex	N1			1.6	
	C3	2.3	2.6			Dissected Residuals	R1	1.3	*	*	*
Dunefields	D1	*	1.7	1.9			R2	*	1.8	*	*
	D2	1.6	1.8	2.5			R3	*	*	1.7	1.7
	D3	*	2.1	2.2			R4	*	1.5		
	D4	2.0	1.9				R5	*	*		
	D5	1.7					R6	1.5	1.6		
	D6	*					R7		*		
	D7	2.1					R8		1.9		
	D8	*				Mulga Sandplains	S1	1.8	1.4	1.6	1.8
Poplar Box Lands	E1			1.8	1.7		S2	2.4	1.8	1.6	
	E2			2.3	1.7		S3		1.7	2.0	
	E3			2.1	3.8		S4		1.7		
	E4			2.1	2.1		S5		2.0		
	E5				2.3		S6		1.7		
	E6				1.8	Wooded Downs	T1		2.4		*
	E7				1.8		T2		2.7		*
Mitchell Grass Downs	F1	*	2.2	2.6	3.3		T3		2.9		
	F2	2.4	2.2		3.0		T4		2.6		
	F3	2.7	3.1		3.1		T5		2.5		
	F4	2.2	*			Alluvial Plains Woodland	W1	2.4	2.5	2.0	*
	F5		2.8				W2	2.6	*	*	2.0
	F6		*				W3	2.9	2.5	2.5	2.6
	F7		2.8				W4	2.1	2.3	*	2.4
	F8		2.1				W5	*	2.8	2.7	2.8
Gidyea Lands	G1	2.1	3.0	3.4	3.0		W6	2.5	2.3	*	
	G2	2.0	3.2	2.3	5.6		W7	2.7	2.5	*	
	G3	2.5	2.4	2.6	3.8		W8			2.7	
	G4	2.5	2.5								
	G5	*									

* Insufficient site data to calculate a rainfall use efficiency for that land system

A blank indicates the absence of that land system from that part of WARLUS.

Table 5.3 Estimated average standard rainfall use efficiencies (SRUE kg/ha/mm) for the 15 land zones from WARLUS Parts I-IV. (* denotes land zone with observations from Chapters 3 and 4).

Land Zone	SRUE (kg/ha/mm)
Alluvial Plains Open (A) *	2.3
Brigalow (B) *	3.5
Channel Country (C)	2.5
Dunefields / Sandhills (D)	1.9
Poplar Box Lands (E)	2.1
Downs (F) *	2.7
Gidgee Lands (G)	2.9
Hard Mulga Lands (H) *	1.8
Claypans / Lakes (L)	2.4
Soft Mulga Lands (M) *	1.8
Spinifex Sandplains (N) *	1.6
Dissected Residuals (R)	1.6
Mulga Sandplains (S) *	1.8
Wooded Downs (T)	2.6
Alluvial Plains Wooded (W)	2.5

5.2.3.2 Estimating the spatial variability in VPD

As rainfall use efficiencies for forages have been shown to be inversely proportional to VPD (Day *et al.* 1993, Scanlan *et al.* 1994), a VPD index (VPDI) was developed to account for the spatial variability in the VPD. The temporal and spatial variability in RUE for a particular land system was examined in Chapter 4. This variation was attributed to seasonal differences in the atmospheric vapour pressure deficit (VPD). However, the impact of spatial variability in VPD was not examined in Chapter 4. An examination of average annual VPD calculated from AUSTCLIM climatic averages of Keig and McAlpine 1969 indicates that in south-west Queensland the annual average VPD increases when moving west and decreases with increasing annual rainfall.

Since the standard rainfall use efficiencies listed in Tables 5.2 and 5.3 were derived using 32 years of Charleville climatic data, the seasonal effect of the VPD on rainfall use efficiency has already been accounted for. To account for the effect of geographical location on the vapour pressure deficit, data for 12 locations from the AUSTCLIM climatic averages (Keig and McAlpine 1969) (Table 5.4) were used to estimate a Vapour Pressure Deficit Index (VPDI) using latitude and longitude (Figure 5.1). As Charleville climatic data were used in simulations, the VPDI was 1.0 at this location.

$$\mathbf{VPDI = 22.997/(190.024+0.2270*Latitude-1.1068*Longitude)\quad R^2=0.96\quad n=12}$$

Table 5.4 Average annual vapour pressure deficits (hPa) from AUSTCLIM for 12 stations used to estimate the VPD index.

Station	Station Number	Latitude	Longitude	VPD (hPa)
Bollon	44010	-28° 2’	147° 29’	20.0
Mitchell	43020	-26° 29’	146° 58’	19.3
Goodooga	48046	-29° 7’	147° 27’	20.4
Tambo	35069	-24° 53’	146° 15’	22.6
Cunnamulla	44026	-28° 4’	145° 41’	22.4
Charleville	44021	-26° 24’	146° 15’	23.1
Thargomindah	45017	-28° 0’	143° 49’	24.9
Blackall	36143	-24° 25’	145° 28’	23.5
Adavale	45043	-25° 55’	144° 36’	24.9
Isisford	36026	-24° 15’	144° 26’	24.8
Quilpie	45015	-26° 37’	144° 16’	24.8
Birdsville	38002	-25° 55’	139° 22’	29.3

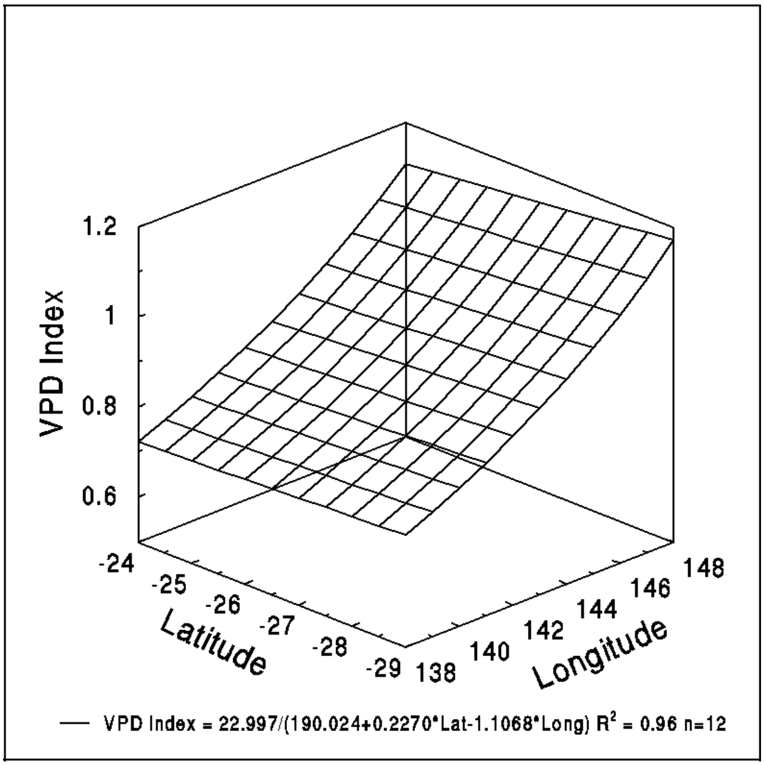

Figure 5.1 A vapour pressure deficit index (VPDI) as a function of latitude and longitude developed from AUSTCLIM average climatic data for 12 locations across south-west Queensland.

5.2.3.3 Estimating the impact of trees and shrubs

Factors such as tree and shrub density and tree and shrub canopy cover, soil erosion, the amount of bare soil and the density of annual and perennial grasses and forbs potentially influence forage production. The impact of tree and shrub density is the well documented (Walker *et al.* (1972), Beale (1973), Scanlan and Burrows (1990), and Scanlan (1991)) and readily assessable in the field. For the estimation of long-term average forage production in south-west Queensland tree and shrub cover was chosen as an indicator of land condition reflecting many of the factors listed above. Areas with high tree and / or shrub cover generally have low soil surface cover and low densities and yield of perennial and annual grasses and forbs. With low levels of soil surface cover they are susceptible to soil loss via water and wind erosion (Miles 1993).

Using step point methodology (Evans and Love 1957), the presence or absence of either a tree or shrub canopy (using a periscope device similar to Buell and Cantlon 1950) was noted at each step to estimate tree and shrub canopy foliage projected cover (FPC (%)) along a transect. The distribution of sampling points across a property was proportional to the areas of the land systems comprising each property. The FPC for each land system was then expressed as woody index (WI).

A number of methods for estimating a woody index existed. These were:

1. Beale's (1971) study examining the effect of different mulga (*Acacia aneura*) densities on forage production at two sites in south-west Queensland and using a site potential of 1000 kg/ha (Figure 5.2).
2. Scanlan's (1984) more general relationship between tree density and forage production established for a range of species (Figure 5.2).

3. Beale's (unpublished) relationship between foliage projected canopy cover and yield potential collected at 97 south-west Queensland sites at the end of the 1994 growing season (Figure 5.3). The major species at these sites were mulga (*Acacia aneura*), poplar box (*Eucalyptus populnea*), green turkey bush (*Eremophila gilesii*), and false sandalwood (*Eremophila mitchellii*). The sites were located on four land systems characterised by sandy-loam red earths. This relationship was comparable to that described by Jameson (1967) based on the sigmoid relationships of Grosenbaugh (1965).
4. Tuning the k value in Scanlan's (1984) more specific relationship to western Queensland conditions. However, the value of k value is a function of site potential and it's applicability to south-west Queensland has not been examined.
5. Using the GRASP model to examine the effects of trees for each site. As the tree component in GRASP was not yet fully validated, this method was not used. The validation of the tree component in GRASP in south-west Queensland has so far been restricted to mulga data (Beale 1971). Further application and validation of GRASP can proceed once all available data have been analysed (e.g. using the first three methods). Whilst it is expected that a process-based model would have greater extrapolation power, such a level of complexity may be unnecessary to achieve the objective of estimating property grazing capacity. Validation using Beale's 97 locations would also require intensive field sampling to estimate parameters for GRASP.

The first three methods were compared to determine the appropriate tree/forage production relationship for estimating forage growth and utilisation across south-west Queensland.

Scanlan's (1984) general relationship did not require extensive testing and validation with specific data for south-west Queensland. It was comparable to results from Beale (1971) when a site production potential of 1000 kg/ha was used (Figure 5.2).

Both authors measured tree density as "tree basal area" (TBA) (m^2/ha). As tree density on the properties used in model development were measured as foliage projected canopy cover (FPC) (%) using a step point and periscope technique, a conversion to TBA was required. To do this, estimates of TBA using a Bitterlich gauge and FPC using the step point technique were made at 14 sites near Charleville. Mulga was the dominant tree species at each site. At each site 100 points were sampled using the periscope to estimate FPC in an area 100m by 100m. Tree basal area was measured using a Bitterlich gauge at five locations within each site. An inverse power relationship between TBA and FPC was estimated (Figure 5.4). This was used to convert Scanlan's (1984) potential yield*TBA relationship to a potential yield*FPC relationship (Figure 5.5).

Examination of these relationships indicate that for mulga communities around Charleville low canopy covers (10%-20%) were associated with tree basal areas in the range 1-5 m^2/ha (Figure 5.4). Within this range a 90% reduction in potential forage was predicted when Scanlan's (1984) general relationship between tree density and forage production was used (Figures 5.5). This relationship may vary for other species and land system combinations.

In comparison, potential yield (WI) was less sensitive to the relationship described by Beale (Figure 5.3). This may be due to the short time period of data collection (end of summer 1994) and the range of tree species/land system/location combinations comprising the FPC data (as opposed to data collected from mulga dominated communities). Regrettably, an analysis of these data for individual species/land system/location combinations has not been made. Such an analysis may remove some of the noise in the data presented by Beale (Figure 5.3) and offer a series of yield/cover relationships for different species/land system/location combinations. Despite this, Beale's "broader" relationship was used as it was considered more appropriate to apply at the paddock and property scale where a range of species are most commonly found. This relationship was also derived using FPC data and did not require a conversion to tree basal area (Figure 5.5) for comparison with forage yield.

$$\mathbf{WI = 1.008 - 0.945 * (1 - e^{(-0.105 * FPC)})^{(0.611 + 1.0)}} \quad (R^2=0.47 \quad n=97)$$

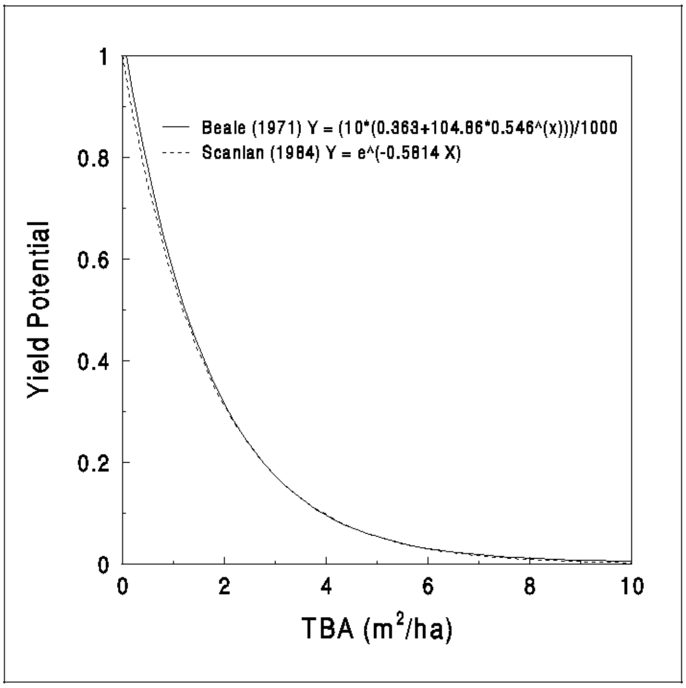

Figure 5.2 Comparison between Scanlan's (1984) and Beale's (1971) relationships between tree basal area (m^2/ha) and forage yield potential.

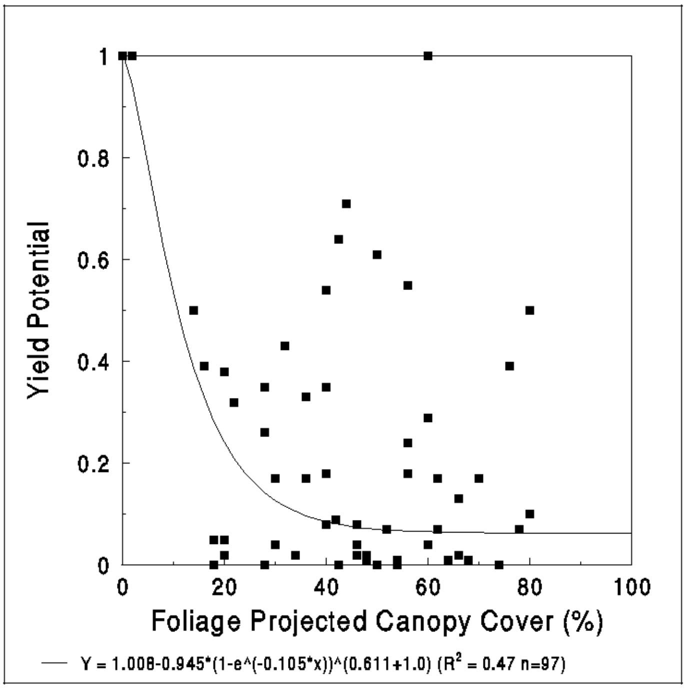

Figure 5.3 The relationship between forage yield potential and foliage projected canopy cover (FPC%) for a range of tree and shrub species on a range of land systems in south-west Queensland (I.F. Beale pers. comm.).

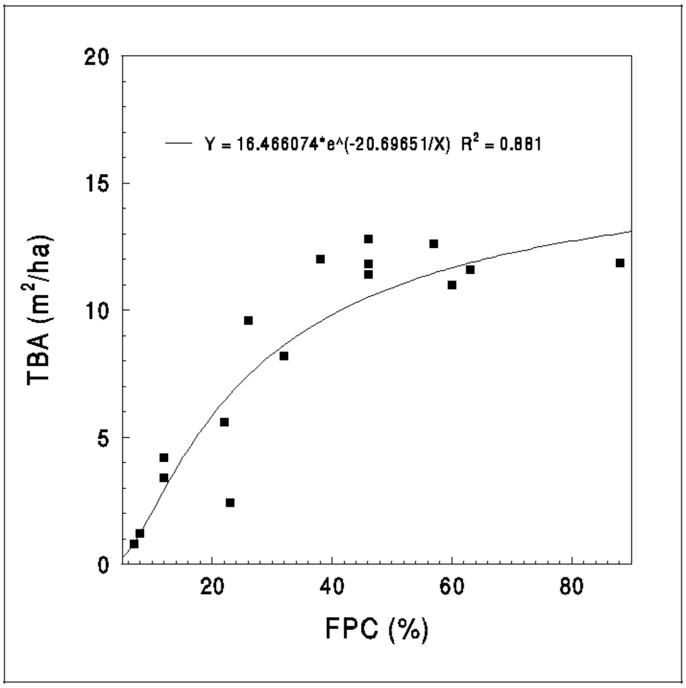

Figure 5.4 The relationship between foliage projected canopy cover (FPC%) of mulga (*Acacia aneura*) and tree basal area (TBA m^2/ha).

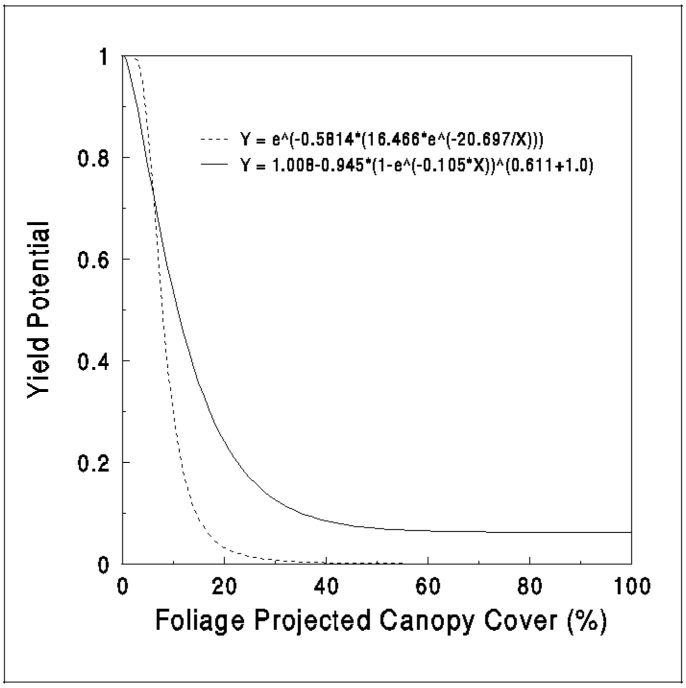

Figure 5.5 A comparison of relationships predicting forage yield potential as a function of foliage projected canopy cover (I.F. Beale pers. comm.___ and Scanlan (1984) ---).

5.2.3.3.1 Estimating the spatial distribution of trees

When estimating forage yield, direct application of each of these relationships assumes an even distribution of trees and shrubs across the landscape. Field observations indicate that trees and shrubs are not evenly distributed across the landscape and that a degree of "patchiness" occurs. Therefore it would be incorrect to apply the relationships derived above evenly over the whole landscape. To examine the spatial distribution of trees, land condition data collected on discrete land systems during an economic survey in south-west Queensland were re-analysed. The results were used to determine the appropriate method to accommodate for patchiness when estimating forage growth at the paddock scale.

The point-based land condition data were originally collected along transects of varying lengths and recorded on field sheets. Each sheet contained the results from 50 points covering an approximate distance of 50m. An average total tree cover (ATC) for each land system was originally estimated as:

$$\textbf{ATC (\%) = No. points with cover / Total points*100}$$

These data were re-analysed to estimate a segment tree cover (STC) for each of the 50m segments as follows:

$$\textbf{STC (\%) = No. points with cover in each segment / 50*100}$$

Forage growth was then estimated for each land system using two approaches: (i) using the average tree cover applied evenly across the entire area of the land system; and (ii) calculating the growth on each segment using the tree cover for that segment and then summing the growth from all segments. The growth estimated by the second approach was assumed to represent a "true" growth accounting for the spatial distribution of trees.

The "true" growth was 1.168 times that of yield estimated from an average cover evenly applied across the landscape (Figure 5.6) (R^2=0.97 n=19). These results indicate that for the land systems examined, trees and shrubs were not evenly distributed across the landscape and that a multiplier of 1.168 was appropriate to use to estimate "true" average growth for the mulga woodlands of south-west Queensland. Similar relationships may exist for other communities. However, the application of this multiplier to specific land systems requires caution as it was developed using data from a range of land systems.

Actual annual forage growth (AAG) for a land system was therefore estimated as:

$$\textbf{AAG (kg) = SRUE (kg/ha/mm) * VPDI * RAIN (mm) * WI * 1.168 * Area (ha)}$$

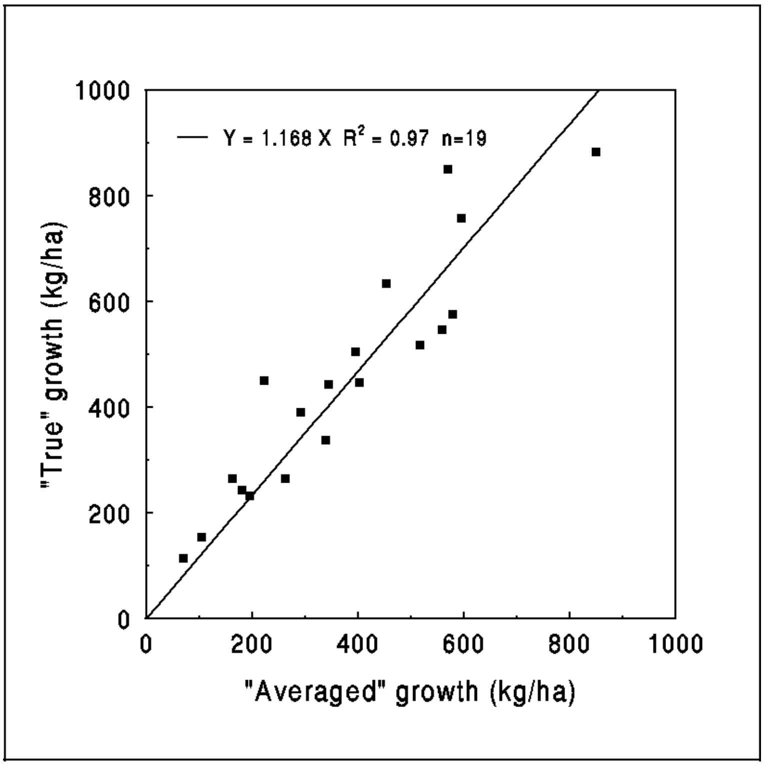

Figure 5.6 The relationship between the forage growth for a land system calculated (i) using an average of the growths estimated from each 50m segment using STC data from each segment and (ii) using ATC data from all transects representing a land system to estimate a singular growth value.

5.2.3.4 Estimating dietary mulga leaf

In mulga woodlands livestock eat a portion of mulga leaf throughout the year (Beale 1975) and as such, the number of livestock supported by leaf fall (DSE_LEAF) has been included in the calculation of grazing capacity. A quantity of mulga leaf litter (LEAF) was calculated based on rates of leaf fall described by Beale (1971). It was estimated that 5% of average annual leaf fall was utilised by livestock (LUTIL). This was based on a long term average proportion of mulga in the diet of 2% (8 kg/DSE/year) and an average annual leaf fall of 150 kg/ha from a stand of mulga with an average FPC of 10%. An annual intake of 600 kg/DSE (LI) for sheep consuming solely mulga was estimated based on voluntary intake of rates of mulga leaf ranging from 500 to 800 kg/DSE/year in pen trials (Miller pers. comm.).

$$\mathbf{LEAF\ (kg/ha) = 16.466 * e^{(-20.697/FPC\ (\%))} * 50.0}$$

$$\mathbf{DSE\_LEAF = (LEAF(kg/ha) * LUTIL\ (\%) * Area\ (ha)) / (LI\ (kg/DSE) * 100)}$$

This method does not account for the browsing of mulga leaf still attached to trees. Such an estimate would require the estimation of the quantity of browsable mulga which varies with the species grazing and the density and structure of the mulga community.

5.2.4 "Safe" level of forage utilisation

In contrast to other approaches to estimating "safe" grazing capacities (e.g. Scanlan *et al.* 1994), three options were explored in this thesis for calculating "safe" utilisation levels of forage grown. Each option relied on the comparison of pasture condition with known levels of utilisation. The first option involved findings from grazing trials which were designed to examine and demonstrate the effects of differences in grazing management on soil, pasture and animal condition. Although grazing trials are "data rich" they have only been conducted on a limited number of land systems. Graziers have experience of a much wider range of land types. Thus, the second option was to use a structured group discussion where the experience of local graziers, researchers and land administrators was pooled to derive a consensus of "safe" forage utilisation for the 15 land zones in south-west Queensland. Land zones represent a grouping of land systems (Dawson 1974). A third option was to examine utilisation levels on selected "benchmark" properties using producer experience to define relative grazing capacities of different land types. The third option only became available during application of the model in the field (Described in Chapter 6). As it complemented the first and second options it has been reported here.

5.2.4.1 Analysis of grazing trials

Five grazing trials from western Queensland were re-analysed using the GRASP model to examine the relationships between the simulated average annual pasture grown and the stocking rates considered safe by the researchers who conducted the trials. The five grazing trials considered (Table 5.5) were relevant to three pasture communities found in south-west Queensland i.e. mulga, mitchell grass and sown gidgee communities. "Safe" levels of utilisation of average annual forage grown thus calculated ranged from 11.7% to 26.4 % (Table 5.5).

In the 20% treatment of the unreplicated Arabella grazing trial, sheep numbers were adjusted to eat 20% of end of summer (April) standing dry matter (kg/ha). Orr *et al.* (1993) reported that reasonable wool production (average 1.245 kg/ha/year greasy wool production) and maintenance of good pasture condition (increased proportions of desirable species, perennial grass basal area > 2% and sufficient dry matter yield to maintain soil cover) was achieved in this treatment. When this grazing trial was analysed using the forage production model GRASP, 20% utilisation of end of summer standing dry matter equated to 15.5% utilisation of simulated average annual forage grown (kg/ha/year over 7 years) (Table 5.5).

Table 5.5 "Safe" treatments in five grazing trials conducted on three western Queensland native pasture communities* used to examine the relationship between utilisation (Util) of average annual forage grown (FG), average annual forage eaten (Eaten) and the maximum observed nitrogen uptake (Nup) as an indicator of site fertility.

Trial Site	Pasture Community *	"safe" Treatment	Reference	FG kg/ha	Eaten kg/ha	Util %	Nup kg/ha
Toorak	Mitchell grass	30% utilisation	Phelps *et al.* (1994)	1608	299	18.6	30.4
Eastwood (Buffel grass)	Gidgee pastures	0.4 ha/DSE	D.M. Orr (pers. comm.)	3222	851	26.4	26.9
Burenda	Mitchell grass	30% utilisation	Beale (1985)	1510	347	23.0	16.0
Arabella	Mulga pastures	20% utilisation	Beale (1985)	580	90	15.5	17.0
Gilruth Plains	Mitchell grass	1 DSE/2ha	Roe and Allen (1945,1993)	1435	168	11.7	16.7

* Native pasture communities as described by Weston *et al.* (1981)

At the Gilruth Plains mitchell grass site it appears the treatment which resulted in an average 11.7% utilisation of forage grown was favoured by the investigators due more for reasons of variability in production than due to evidence of damage to pastures. From the perspective of resource maintenance, the heavier stocking treatment which equates to a calculated 23.4% utilisation appeared to be a “safe” treatment. If this is a correct interpretation of the findings of these trials, “safe” utilisation levels (as defined in this thesis) ranged from 15.5% to 26.6 % of average annual forage grown with an average of 22.4% across these trials.

5.2.4.2 Consensus data

A group consisting of two experienced graziers, two Department of Primary Industries staff and a Department of Lands officer, reached a consensus on their estimates of a “safe” level of utilisation for each of the 15 land zones in south west Queensland (Table 5.6). The range of 15% to 20% utilisation considered safe by consensus was similar to the range found for grazing trials (above). Whether the utilisation levels for each land type may be related to the productivity of the land types as reflected in the SRUE was then investigated. A linear regression between an index of SRUE and utilisation proved significant ($P<0.05$) but accounted for only 59% of the variability in utilisation (Figure 5.7).

Table 5.6 Estimates of “safe” levels of utilisation of average annual forage grown using a consensus approach for 15 land zones (Dawson 1974, Mills and Lee 1990) in south-west Queensland.

Land Zone	“Safe” Utilisation (%)
Alluvial Plains Open (A)	20.0
Brigalow (B)	20.0
Channel Country (C)	17.5
Dunefields / Sandhills (D)	15.0
Poplar Box Lands (E)	15.0
Downs (F)	20.0
Gidgee Lands (G)	17.5
Hard Mulga Lands (H)	15.0
Claypans / Lakes (L)	15.0
Soft Mulga Lands (M)	15.0
Spinifex Sandplains (N)	15.0
Dissected Residuals (R)	15.0
Mulga Sandplains (S)	15.0
Wooded Downs (T)	20.0
Alluvial Plains Wooded (W)	17.5

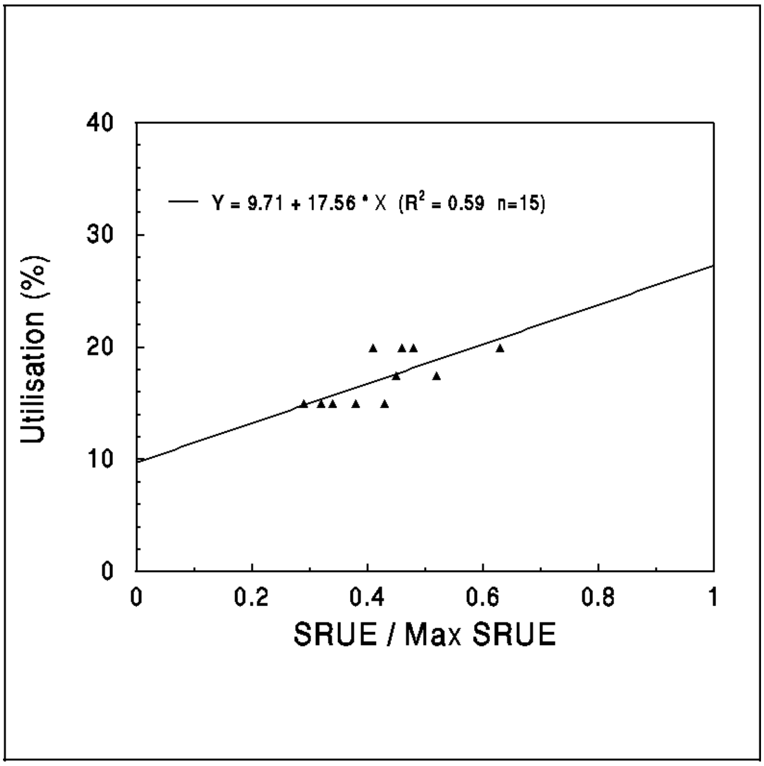

Figure 5.7 The linear relationship between "safe" levels of forage utilisation derived from consensus data and an index of land system fertility (ratio of land zone rainfall use efficiency to maximum standard rainfall use efficiency (SRUE)).

5.2.4.3 Selected benchmark properties and grazier experience

Following discussions with experienced graziers, Department of Lands and Department of Primary Industries staff, three "benchmark" properties were chosen to examine "safe" levels of forage utilisation on the assumption that the grazing strategies on these properties were "safe" (Figure 5.8). These properties were considered to be in "good condition" with relatively stable livestock numbers (27, 19 and 21 DSE/km^2 respectively). The selection of properties was necessarily subjective. Detailed surveys of the land and pasture condition on these properties have not been conducted (apart from tree and shrub FPC %). Had such data been available it still would not have been possible to quantitatively compare the condition of the properties with others in south-west Queensland due to the lack of regular regional scale monitoring in the region.

Actual average livestock numbers for each "benchmark" property were obtained from the graziers. However, these data were only available at the property level. As land systems provide the basis for extrapolating resource and management information from one property to another it was necessary to convert this property level livestock data to a land system level. The grazier's experience was used as a basis to rate the relative grazing capacity of each land system on the property. The average livestock numbers were then apportioned to land systems based on these grazier ratings. Average annual forage grown and the FPC % of trees and shrubs was calculated for each land system on each property by using the approach described above.

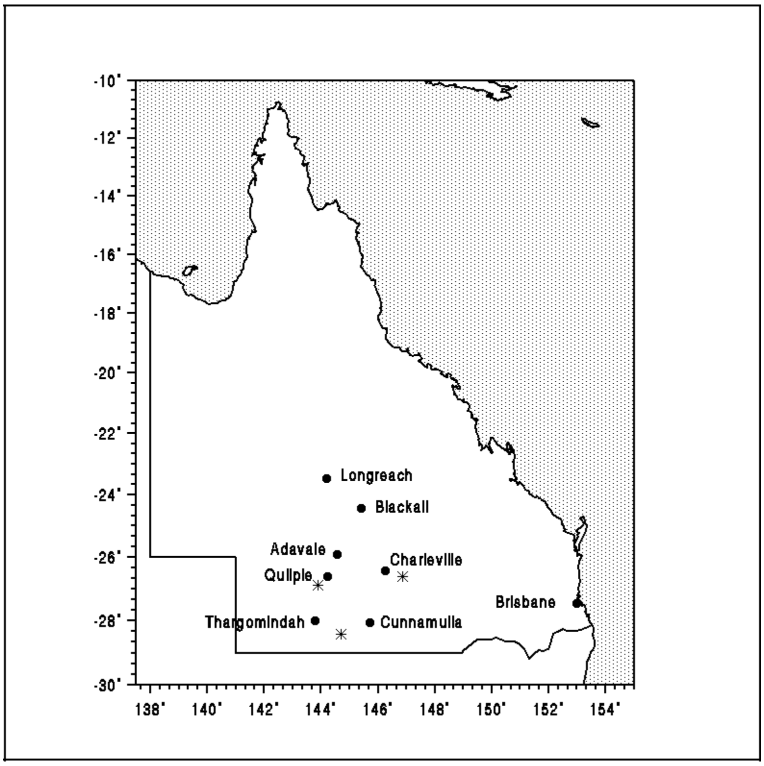

Figure 5.8 Location of the three benchmark properties (*) used to estimate "safe" levels of utilisation of estimated average annual forage grown in south-west Queensland.

Thus with an estimate of average annual forage grown and average livestock numbers for each land system (Figure 9a), utilisation was calculated (Figure 9b). As the properties were considered to be in good condition, it was assumed that the utilisation (SUTIL) of average annual forage grown (FG) on these properties and land systems was "safe":

$$\textbf{SUTIL (\%)} = \textbf{((DSE * Intake (kg/DSE)) / FG (kg)) * 100}$$

The average utilisation of average annual forage grown across all land systems and properties was 21.3% (n=38, range = 8.4%-41.7%, SE = 1.7). This average agreed with that for consensus data and grazing trials. However the range in utilisation was wider. This higher variation is to be expected given (1) the greater number of observations and (2) the estimates were made by individual graziers and, as such, were not "averaged" by consensus.

An alternative examination of the above equation using a linear regression forced through the origin indicated a slope of 0.172 (R^2 = 0.93 n=38) between total intake (kg/ha) and average annual forage grown (kg/ha) (Figure 9b). This equates to a utilisation level of 17.2%.

In an attempt to further account for the observed variation in utilisation levels across land systems, as with the consensus data presented above, the relationship between SRUE and utilisation was examined. In this case a significant ($P<0.05$) negative relationship was found between utilisation and SRUE:

$$\textbf{SUTIL (\%)} = \textbf{19.832 - 1.193 * SRUE (kg/ha/mm)} \quad (R^2 = 0.56 \;\; n = 38)$$

However, this relationship described the pattern of estimated utilisation across the land systems on the three benchmark properties. It was based on the individual grazier's perception of the grazing capacity for each land system and not what actually was grazing each land system. It indicates less fertile land systems with smaller SRUE's experienced higher levels of utilisation. This may be due to greater quantities of browse being available on these land systems thereby contributing to a perceived greater grazing capacity. The actual grazing derived from each land system is also difficult to determine due to different grazing preferences exhibited by livestock across the landscape in relation to water location, wind direction and vegetation preference (Landsberg *et al.* 1992).

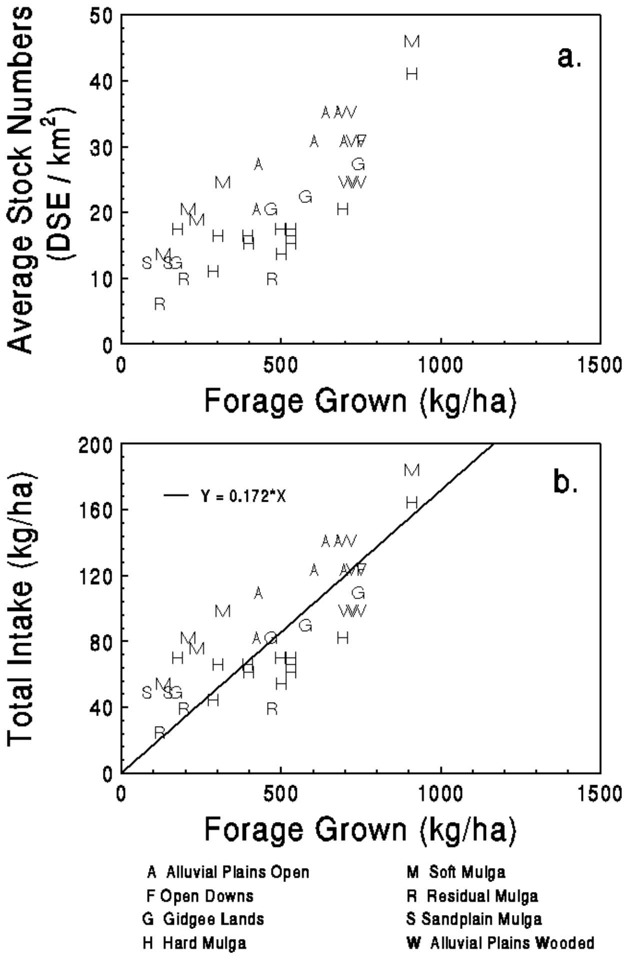

Figure 5.9 The relationship between (a) average livestock numbers (DSE/km^2) and average annual forage grown (kg/ha) and (b) average annual total intake (kg/ha) and average annual forage grown (kg/ha) on the 38 land systems on the 3 benchmark properties used to estimate 'safe' levels of utilisation of forage grown in south-west Queensland (Letters denote land zones described by Dawson (1974, Mills and Lee 1990)).

5.3 Estimating a grazing capacity

The three sources of information examined (grazing trial, consensus and "benchmark" property) point to a "safe" "average" level of utilisation of approximately 17% but, depending on individual perceptions and land type, "safe" utilisation might expect to range from 15% to 25%. For the purpose of deriving a single figure or relationship for inclusion in the carrying capacity calculation the consensus data were chosen. This choice was made on the basis that this best represented a shared and, an assumed, fair and balanced view. Rather than take an average utilisation value (17%) it was assumed that a hypothetical relationship existed between pasture fertility (as measured by SRUE) and a "safe" level of utilisation. A linear relationship between "safe" utilisation and an index of SRUE was significant (Figure 5.7). While this was true over the range of SRUE values examined, the methodology described in this thesis is likely to be used and evaluated beyond this range of fertility (SRUE). Given that such extrapolation is likely, a choice was made to err on the side of caution in calculating safe utilisation levels at extreme (high and low) values of SRUE. Thus the function fitted to the consensus data (Figure 5.10) was:

SUTIL (%) = (SRUE/Max SRUE)/(0.0340*(SRUE/Max SRUE) + 0.0102) (R^2=0.57 n=15)

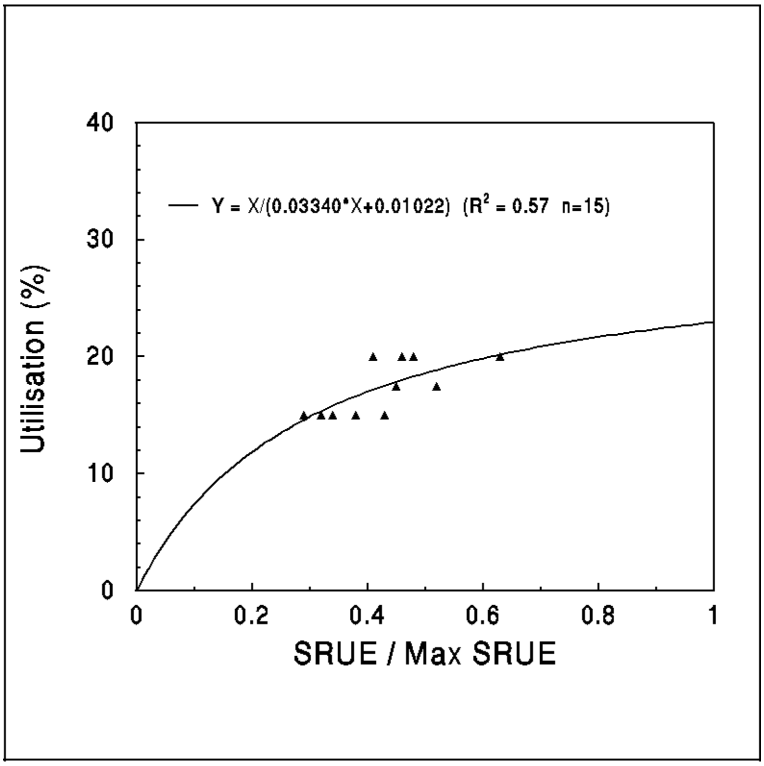

Figure 5.10 The hypothesised curvilinear relationship between 'safe' levels of forage utilisation derived from consensus data and an index of land system fertility (ratio of land zone rainfall use efficiency to maximum standard rainfall use efficiency (SRUE)) used in the calculation of 'safe' grazing capacities for individual properties in south-west Queensland.

For extremely infertile sites the view was taken that grazing should only be conducted with very careful attention to stock numbers. The relationship therefore chosen was one which reduces safe utilisation to zero as SRUE approaches zero. In choosing this relationship it is emphasised that there is no "biological" implication in choice of this function and no supporting data is presented. As such this choice of function simply reflects a conservative attitude to risk taken in this thesis.

For extremely fertile sites it is likely that other factors (e.g. rainfall variability) are likely to limit safe levels of utilisation. The plateau in the above relationship (Figure 5.10) reflects this assumption and, as such, provides a conservative safe utilisation level at high SRUE.

5.4 Sensitivity analysis

A sensitivity analysis was performed to assess the reliability and sensitivity of different components of the model. Each coefficient in each of the above relationships was varied by ± 10% and the resulting variation in grazing capacity expressed as a percentage.

The grazing capacity estimate was most sensitive to the second and fourth coefficients describing the vapour pressure deficit index (VPDI) (>10% change in grazing capacity with a 10% variation in any one coefficient) (Table 5.7). This indicates the VPDI needs to be estimated most reliably and that application of the approach outside south-west Queensland (based on the 12 AUSTCLIM stations from Table 5.4) requires caution. The grazing capacity estimate was also sensitive to the first coefficient describing the woody index (1.008). This coefficient defines the slope of the negative exponential where it is most sensitive to change in the FPC (0-30%) and places importance on the analysis of the data conducted by Beale (pers. comm.) illustrated in Figure 5.3. The sensitivity to this coefficient supports further analysis of these data as indicated in Section 5.2.3.3 to establish a series of relationships for different species, land system combinations. For other coefficients and input values a ± 10% change resulted in a less than 10% variation in the grazing capacity.

Table 5.7 Sensitivity analysis examining change in grazing capacity (%) for individual land systems following a ± 10% variation in coefficients and selected input data in the equations used to estimate a grazing capacity.

Equation	Coefficient	Change (%) resulting from: +10%	-10%
Equation coefficients			
VPDI	22.997	9.50	-9.50
	190.024	-43.93	650.00
	0.2270	1.39	1.35
	1.1068	289.04	-40.58
WI	1.008	10.23	-121.08
	0.945	-3.80	3.80
	0.105	-6.35	6.60
	0.611	2.46	-2.72
SUTIL	0.03340	-4.35	4.81
	0.01022	-4.68	5.22
	5.6	-4.68	5.22
LEAF	16.466	0.50	-0.50
	20.697	-0.71	0.85
	50.0	0.50	-0.50
Input data and equation results			
SRUE		9.50	-9.50
VPDI		9.50	-9.50
SUTIL (%)		9.50	-9.50
LEAF (kg)		0.50	-0.50
RAIN (mm)		9.50	-9.50
Tree FPC (%)		-3.94	3.97
Shrub FPC (%)		-2.24	2.36

5.5 Estimating grazing capacities on 46 individual properties

For 46 properties surveyed in south-west Queensland in 1989 (Passmore 1990) (Figure 5.11), actual forage growth was calculated for the years in which livestock data were available using the method described above. Land condition was estimated from December 1989 to January 1990 using the step point method (Evans and Love 1957). The 2000 step points per property were stratified in proportion to the areas of different land systems. A grazing capacity was then estimated for each property and compared to actual stocking rates over the survey period (sheep and cattle numbers expressed as DSE). The calculated grazing capacity and actual stocking rates were also compared to the Department of Lands rated carrying capacities. These values were obtained from the Charleville and Cunnamulla district offices. They were determined from settlement up to the 1940's and 1950's through local experience, early stock returns and what stock the properties carried over that period (P.R. Tannock pers. comm.)

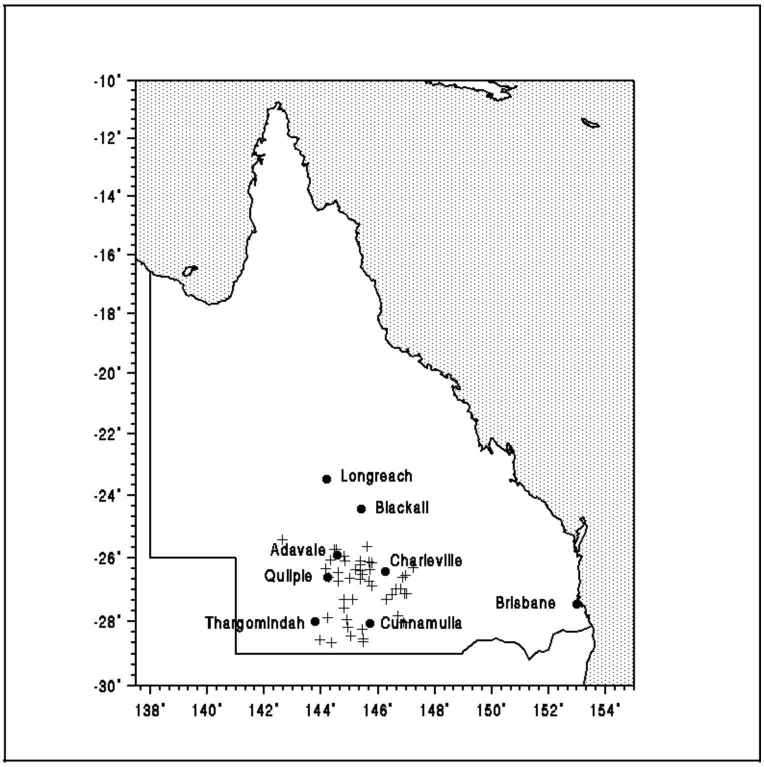

Figure 5.11 Location of the 46 properties of Passmore (1990) for comparison of actual stocking rates and calculated grazing capacities for the years 1986 to 1988 in south-west Queensland.

5.5.1 Forage utilisation in south-west Queensland

For the 46 properties utilisation of average annual forage growth (April to March) by domestic stock was 33.5% for the years 1986 to 1988 (Figure 5.12). There was little variation between years (32.4% to 34.6%). This reflects the small variation in rainfall (average 385mm, range 375-402mm, long-term average 400mm) and subsequent calculated forage growth (average 542 kg/ha) for this period.

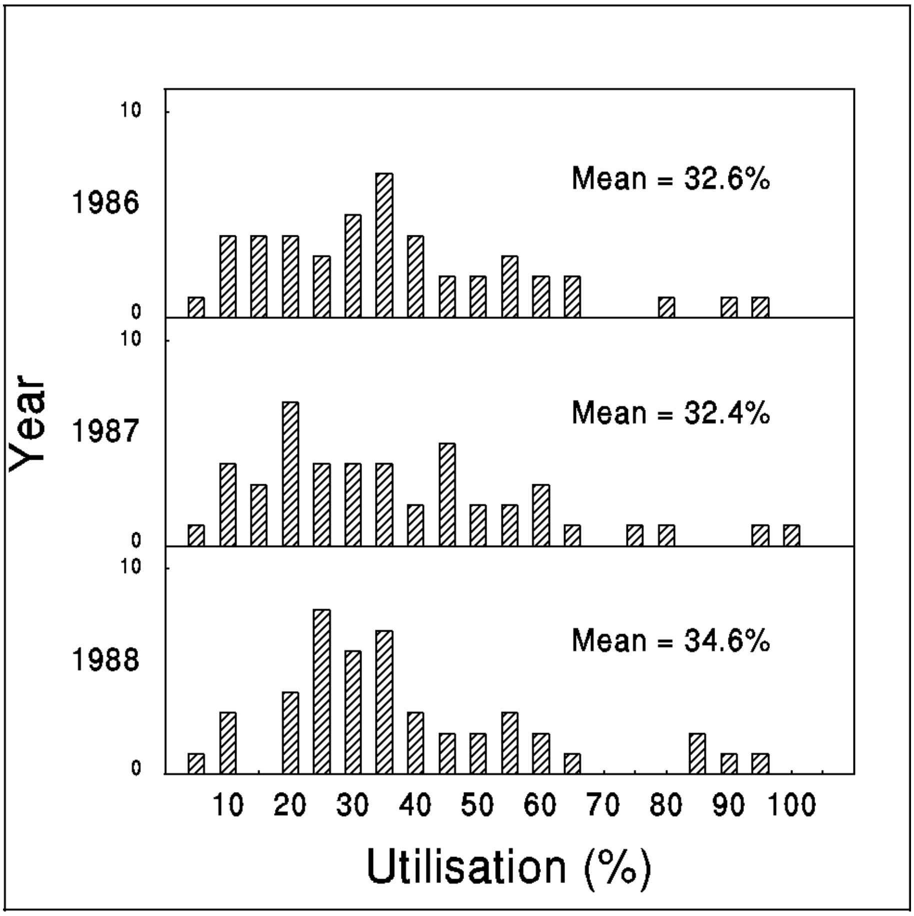

Figure 5.12 Frequency distribution of forage utilisation for the years 1986 to 1988 across the 46 properties of Passmore (1990) in south-west Queensland using actual rainfall and livestock numbers.

An examination of utilisation of calculated average regional forage growth masks the high degree of variability in utilisation between properties. Utilisation of annual (April to March) forage growth ranged from 5 to 100% for the years 1986 to 1988 with 86% of properties exceeding 17.2% utilisation (Figure 5.12).

Using the average stock numbers for the 1986 to 1988 period and long-term average rainfall, 17.2% utilisation was exceeded on 83% of properties and 20% utilisation exceeded on 78% of properties (Figure 5.13a). Using the Department of Lands rated carrying capacities and long-term average rainfall, 17.2% utilisation was exceeded on 91% of properties while only 72% of properties exceeded 20% utilisation (Figure 5.13b).

The majority of flocks increased in size from 1986 to 1987 and from 1987 to 1988 (Figure 5.14). However, change in flock size was not significantly correlated to forage utilisation in the preceding year (R^2=0.025, n=92, P<0.05) (Figure 5.14).

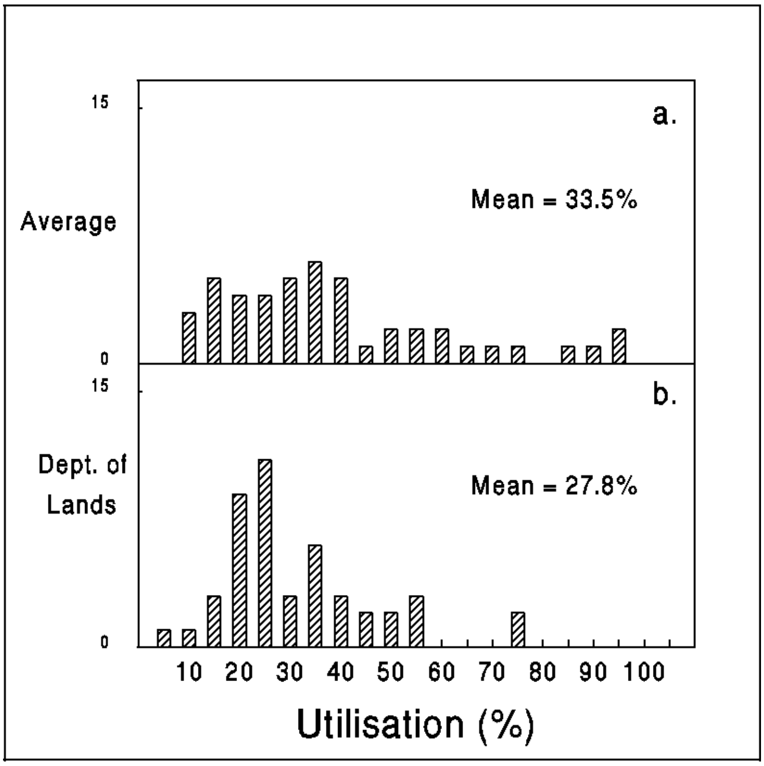

Figure 5.13 Frequency distribution of forage utilisation for 46 properties in south-west Queensland using long-term average rainfall and average livestock numbers for each property for the period 1986 to 1987 (a.), and Department of Lands rated livestock numbers (b.).

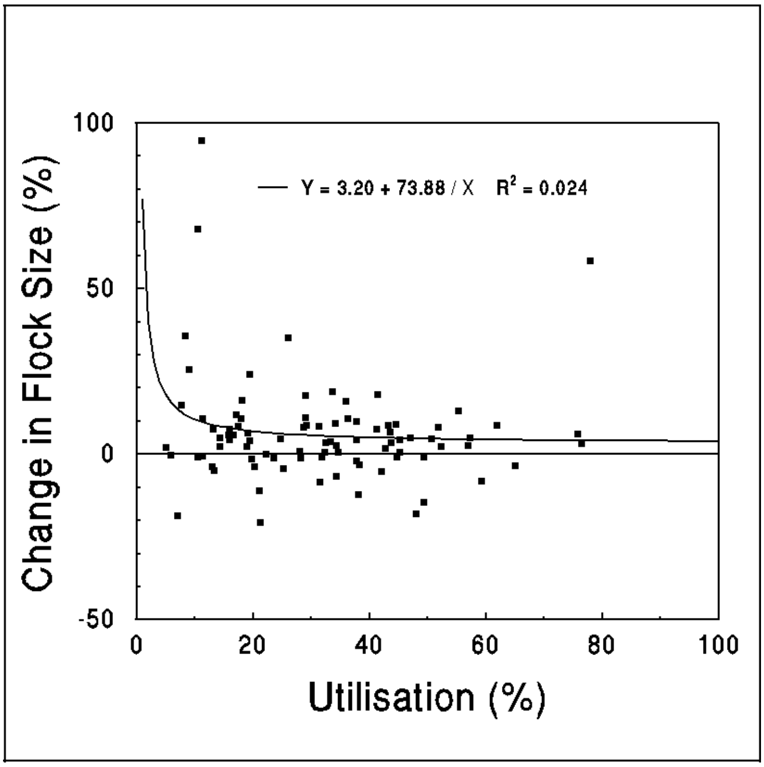

Figure 5.14 Annual change in flock size (%) in relation to forage utilisation (%) for 1986 to 1987 and 1987 to 1988 for 46 properties of Passmore (1990) in south-west Queensland. There was no significant relationship between change in flock size and utilisation.

5.5.2 Comparison of stocking rate and calculated grazing capacity

The ratio of actual average stocking rate to calculated grazing capacity (0.6 to 9.6) was not significantly correlated to property size (Figure 5.15a) or flock size (Figure 5.15b). Five of the 46 properties in the 1986 to 1988 period were stocked at the calculated grazing capacity or below it (ratio < 1.0).

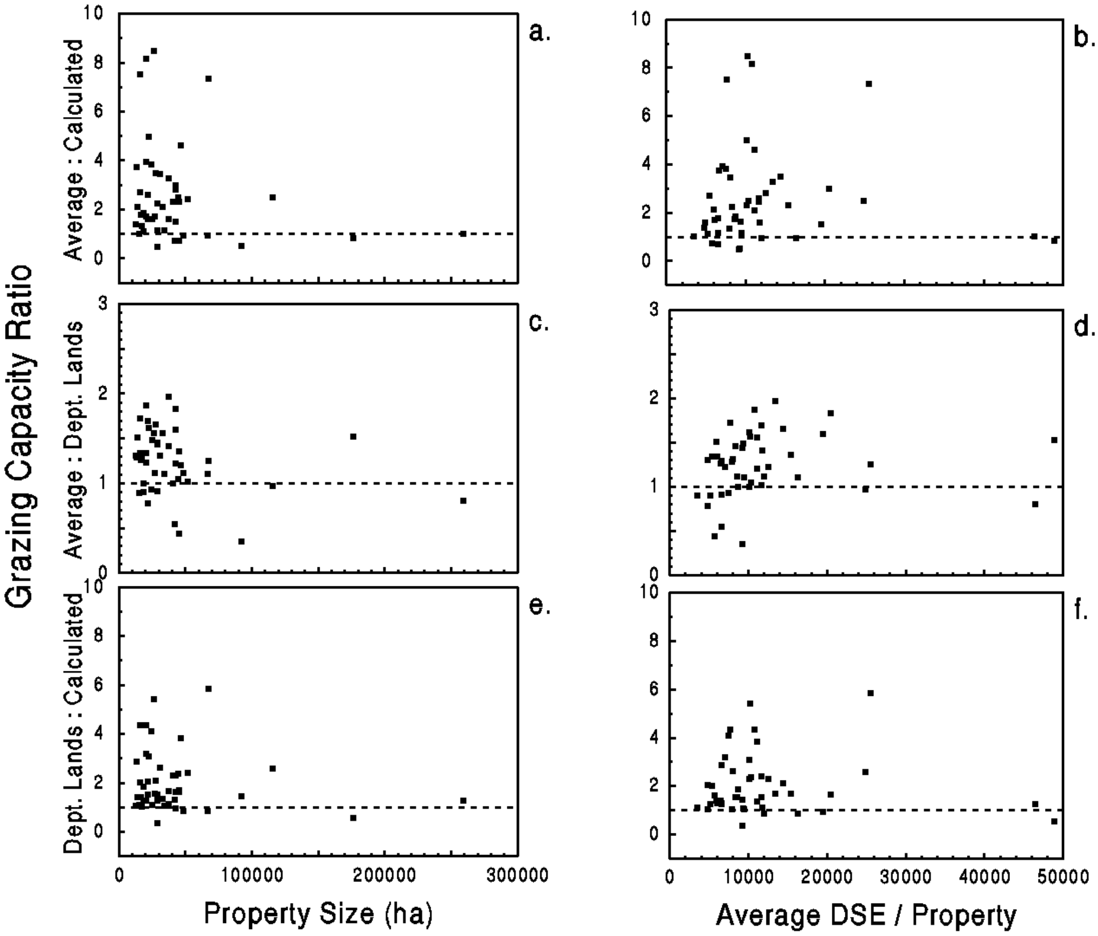

Figure 5.15 Comparison of livestock ratios (a) owner livestock numbers : calculated grazing capacity and property size, (b) owner livestock numbers : calculated grazing capacity and flock size, (c) owner livestock numbers : Department of Lands rated carrying capacities and property size, (d) owner livestock numbers : Department of Lands rated carrying capacities and flock size, (e) Department of Lands rated carrying capacities : calculated grazing capacity and property size and (f) Department of Lands rated carrying capacities : calculated grazing capacity and flock size for 46 grazing properties in south-west Queensland during the period 1986 to 1988.

The ratio of actual average stocking rate to the Department of Lands rated carrying capacity (0.4 to 2.0) was not significantly correlated to property size (Figure 5.15c) or flock size (Figure 5.15d). Twelve of the 46 properties in the 1986 to 1988 period were stocked at or below the Department of Lands rated carrying capacity (Figure 5.15c and 5.15d).

The ratio of Department of Lands rated carrying capacity to calculated grazing capacity (0.4 to 6.2) was not significantly correlated to property size (Figure 5.15e) or flock size (Figure 5.15f). On four of the 46 properties the Department of Lands rated carrying capacity was at or below the calculated grazing capacity (Figure 5.15e and 5.15f).

The ratio of actual average stocking rate to calculated grazing capacity (0.6 to 9.6) was not significantly correlated to the proportion of bare ground, litter cover, presence of soil erosion, perennial grass cover or forb cover as estimated in the step point survey of land condition (Figure 5.16). Shrub and mulga cover were not compared as they were mathematically related to the calculated grazing capacity.

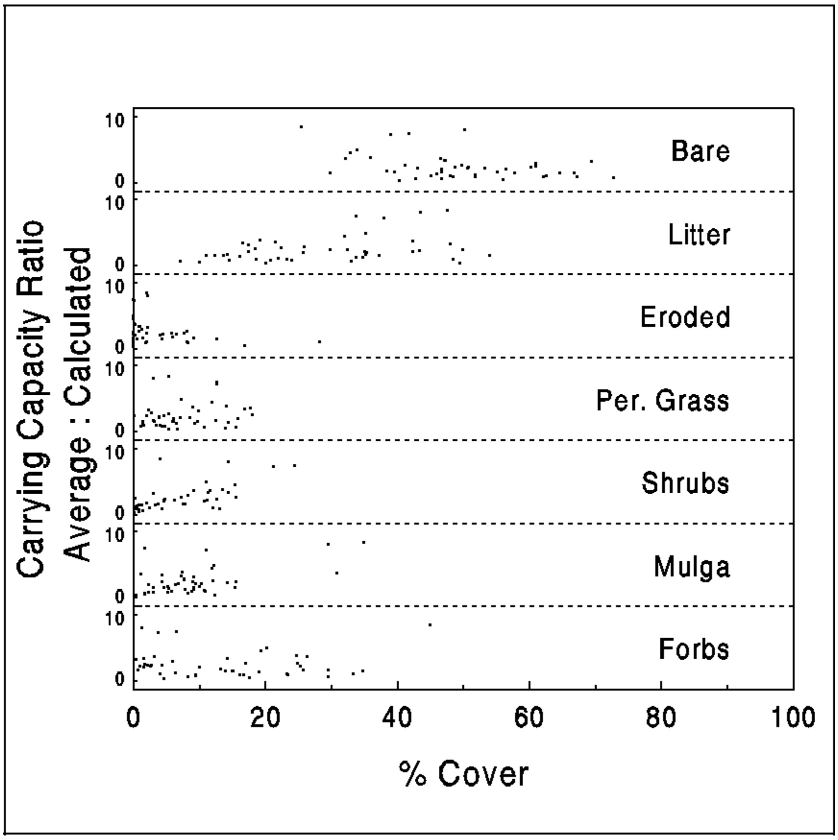

Figure 5.16 The ratio of average livestock numbers to calculated "safe" livestock numbers in relation to 7 measures of land condition (cover %) on the 46 properties of Passmore (1990) in south-west Queensland during the period 1986 to 1988.

5.6 Discussion

Estimation of average annual forage growth using rainfall use efficiencies, coupled with independent estimates of "safe" levels of forage utilisation (grazing trials, consensus data and 'benchmark' properties), provided an ecological basis for examining grazing capacities on individual properties in south-west Queensland. This Chapter has developed links between science, "benchmark" grazing practice and local experience within an ecological framework to derive a method for estimating grazing capacities of individual properties. Such links are necessary if grazing lands are going to meet the increasing variety of needs society places upon it (Walker 1995).

The approach to estimating grazing capacities enabled a preliminary examination of the 46 properties for which production and land condition data were available (Passmore 1990). The correlation between calculated grazing capacities and actual stocking rates may be improved by refinements identified by Scanlan *et al*. (1994) which include; accounting for spatial variability in resource use by grazing animals, complete accounting for the effects of land condition on forage growth, accounting for the forage consumed by native and feral herbivores, better estimates of "safe" levels of utilisation for different land systems, and improved methods to estimate potential forage growth. As "benchmark" properties were used, the methodology is considered sound even if these factors were not fully accounted for. The key is that the level of influence of these factors is considered the same on the "benchmark" properties as on the other 46 properties.

For the period 1986 to 1988 (a period of average rainfall), livestock numbers on 34 of the 46 properties exceeded the Department of Lands ratings at that time. This indicates the consensus that Department of Lands rated carrying capacities for the mulga zone are higher than those practiced by graziers does not hold. The Department of Lands rated carrying capacities in the mulga zone have been under review since 1989 and results here indicate that current rated capacities are more conservative than actual stocking rates. However, the Department of Lands values were higher than those calculated, and in the long-term could result in 91% of properties exceeding 17.2% utilisation of average growth. As there was no relationship between the Department of Lands values and either the actual or calculated capacities, a review of these values may be warranted if these values are to be used in the administration of leasehold properties (Scanlan *et al*. 1994), or as a guide for the purchase or disposal of properties. This has major implications for the economy of the region as the value of a property is largely determined by its grazing capacity (Holechek *et al*. 1995). For south-west Queensland in the mid 1990's this ranges from $27-$40 per sheep area.

The methodology proposed in this chapter to estimate "safe" long-term grazing capacities assumes average annual utilisation of average annual growth by domestic livestock should not exceed 15%-25%. This was supported by grazing trials in which term wool production and resource stability was achieved at 20% rather than higher levels of utilisation of end of summer standing dry matter (Orr *et al*. 1993) (equating to an average 15.5% utilisation of annual growth). If grazing management used forage utilisation concepts in stocking rate decisions then flock sizes would increase as forage utilisation declined and decrease when forage utilisation increased. In an ideal scenario, a compromise between a "safe" constant stocking policy and a flexible policy based on utilisation as described by Wilson *et al*. (1990) could be achieved. Under such a scenario a long-term average of the flexible policy would approximate that of the "safe" constant policy.

However, it is possible that, under a flexible stock management policy, a higher level of utilisation may be "safe" than if stock numbers were kept constant. This could occur if the stocking rate (in the short term) matched pasture growth, thereby avoiding critical periods of pasture damage. This is an area requiring further research for land systems in south-west Queensland.

For the larger group of 46 properties there was no significant relationship between change in flock size and level of forage utilisation. This indicates stock numbers fluctuated with little regard for the level of forage utilisation and that high levels of utilisation were practiced by most of the grazing industry in south-west Queensland over the 1986 to 1988 period.

The ability of livestock to survive at such high levels of utilisation is most likely due to the availability of mulga as browse. Without browse high livestock losses would be anticipated. However, the exact contribution of mulga to the diet of stock over the study period was unknown. It is also unclear as to what level of forage utilisation that stock begin to rely on mulga as a food source. In a grazing trial conducted near Charleville (Beale 1985), where sheep numbers were adjusted annually at the end of summer (April) to eat 80% of the available forage, calculated average utilisation of growth did not exceed 39% (Figure 5.17). In this trial, mulga was only available as browse (not felled for livestock) and sheep were removed from the trial based on liveweight to avoid deaths. However, as a result of heavy grazing (39% utilisation) in this treatment a detrimental change in pasture composition and grass density was observed (Orr *et al.* 1993). In paddocks on properties where reliance on mulga (either as browse or felled) results in prolonged periods of high utilisation detrimental changes to pasture composition would therefore be expected. Orr *et al.* (1993) indicate this has important implications for pasture recovery following heavy grazing. Experimental evidence (Brown 1986 and 1987) indicates that any recovery of desirable species may be difficult to achieve and the chances of woody weed invasion are more likely. On the properties experiencing high levels of forage utilisation it was unknown whether mulga was being fed to livestock, whether deaths were above average and whether pasture deterioration was occurring (lack of correlation between the ratio of actual average stocking rate to calculated grazing capacity and land condition (Figure 5.16)). However, the land condition data presented here was from a single survey. It would be desirable to compare the calculated ratio to change in land condition or more importantly to change in livestock productivity as described by Abel and Blaikie (1989). However, regional surveys of land and pasture condition (Mills *et al.* 1989) indicate pasture deterioration and woody weed invasion was occurring. The availability of mulga as browse can therefore be considered a factor contributing to land and pasture degradation in south west Queensland.

Similarly, dietary supplements used in the beef industry to sustain livestock production have also contributed to land and pasture degradation in the dry tropics of northern Australia (Gardener *et al.* 1990).

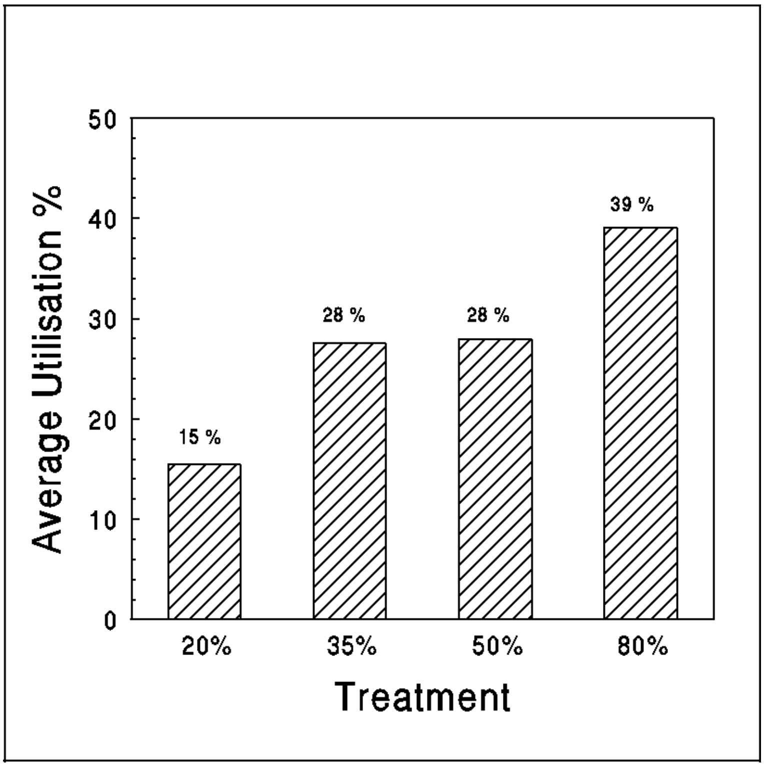

Figure 5.17 Utilisation (%) of calculated average forage growth (kg/ha) in the four treatments (20%, 35%, 50% and 80% utilisation of end of summer standing dry matter) in the Arabella grazing trial (Beale 1985) conducted near Charleville.

A potential factor contributing to increasing flock sizes, and high levels of utilisation during the study period was the rapid increase in the value of wool over this time (Figure 5.18). It would be worthwhile to compare the costs and benefits associated with the increased wool prices and risks of land and pasture degradation. This would require detailed economic analyses linking the costs of pasture degradation to future productivity and is beyond the scope of this thesis.

In contrast to Scanlan *et al.* (1994) there was no relationship between property size and the ratio of actual stocking rate to "safe" grazing capacity. The smaller properties sampled (< 20000 ha) were both heavily and lightly stocked (ratio range 1.1-8.2). The larger properties (> 40000 ha) also experienced heavy and light stocking regimes (ratio range 0.5-7.8). However, only five of the 46 properties were stocked more conservatively than the calculated capacity. This included both small and large properties, indicating that potential problems associated with high grazing pressures and ensuing land degradation were not confined to the smaller properties. This suggests the problems of land degradation will not be solved by merely increasing average property size while current stocking practices exist. Many factors determine a stocking policy for a particular property. These include commodity prices, debt level, lifestyle preferred, attitude to risk, off farm income, rainfall and suitability of resources. However, if potential problems regarding land degradation are to be addressed, the concept of applying "safe" levels of forage utilisation is central to grazing capacity decision making regardless of property size.

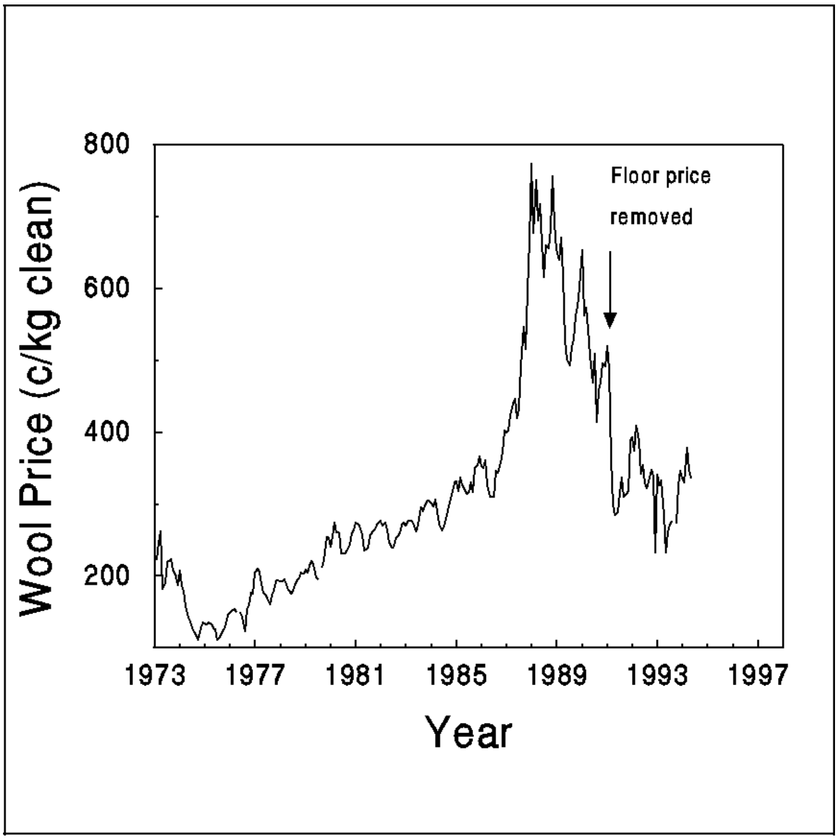

Figure 5.18 The fluctuation in wool prices (c/kg clean) from 1973 to 1994. (Source: The National Council of Wool Selling Brokers of Australia).

5.7 Conclusions

The methodology developed to estimate "safe" grazing capacities was based on ecological principles. It is repeatable and can be applied to any property in south-west Queensland or to other regions of the state where rainfall is the major factor influencing forage production and appropriate data are available. The repeatability of the method enables it to be applied to individual properties to provide an individual "safe" grazing capacity for that property. This alleviates the problems of inaccurate estimates of a grazing capacity for a property when based on district average capacities. The repeatability of the method also enables the review of "safe" grazing capacities if changes in land condition (tree and shrub density at this stage) or forage production occur for a particular property or land system on the property. Other factors such as the impact of soil loss or change in botanical condition could be include in the methodology as the relationships between these factors and forage production are defined.

If land managers and land administrators used the approach developed here to assess grazing capacity, improved land management practices may follow as a result of better informed decision making. Coupled with financial and economic analyses for aggregations, improved estimates of appropriate property size could be examined using the methodology. The determination of "living areas" would then have a quantifiable basis. Definition and implementation of drought assistance policies could also be improved with use of the methodology. Instances where disregard for resource capability and seasonal conditions inducing early "droughts" could be better identified. The method would also enable the assessment of the financial impacts and risk flowing from changes in commodity prices and cost structures associated with rural industry.

There is room for further refinement of the methodology requiring a commitment from researchers and funding bodies. At this stage the methodology provides a framework for examining long-term or 'strategic' decisions regarding domestic livestock numbers. Native and feral grazing animals have not been included in the estimation of grazing capacity. The methodology focuses on 15% to 25% utilisation of average annual forage growth by domestic livestock as being "safe" and assumes an average long term (20-30 years) uniform distribution of feral and native herbivores. However, the inclusion of native and feral grazing animals in the methodology would facilitate the examination of total grazing pressure. From a land stability viewpoint total grazing pressure and its management is critical. However, any improvements must adhere to the ecological principles developed and focus on utilisation as the measure of sustainability. With such an approach, our understanding of the production variability associated with grazing in south-west Queensland, and our ability to "safely" use the resource will be improved.