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OBJECTIVE 'SAFE' GRAZING CAPACITIES FOR SOUTH-WEST QUEENSLAND AUSTRALIA: DEVELOPMENT OF A MODEL FOR INDIVIDUAL PROPERTIES

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Abstract

Few tools are available to assist graziers, land administrators and financiers in making objective grazing capacity decisions on Australian rangelands, despite existing knowledge regarding stocking rate theory and the impact of stocking rates on land condition.

To address this issue a model for objectively estimating 'safe' grazing capacities on individual grazing properties in south-west Queensland was developed. The method is based on 'safe' levels of utilisation (15%-20%) by domestic livestock of average annual forage grown for each land system on a property. Average annual forage grown (kg/ha) was calculated as the product of the rainfall use efficiency (kg/ha/mm) and average annual rainfall (mm) for a land system. This estimate included the impact of tree and shrub cover on forage production. The 'safe' levels of forage utilisation for south-west Queensland pastures were derived from the combined experience of (1) re-analysis of the results of grazing trials, (2) reaching a consensus on local knowledge and (3) examination of existing grazing practice on 'benchmark' grazing properties.

We recognise the problems in defining, determining and using grazing capacity values, but consider that the model offers decision makers a tool that can be used to assess the grazing capacity of individual properties.

Introduction

There is considerable debate in the literature over the definition, derivation and use of grazing capacity values (Bartels *et al.* 1993). Nevertheless, graziers, land administrators and financiers need to make strategic decisions on grazing capacity (20-30 years) and tactical decisions regarding stocking rate (seasonally or annually). While stocking rate theory (e.g. Jones and Sandland 1974, Hart 1978, 1986, Danckwerts 1984, White 1987, Turner and Tainton 1989, Vallentine 1990, Heitschmidt and Taylor 1991, Abel 1992, Behnke and Scoones 1993 and Holechek *et al.* 1995) and the impact of stocking rates on rangelands (see Ash and Stafford Smith 1996) has been examined worldwide, there are few practical tools available to guide the estimation and implementation of sustainable grazing capacities. Most rely on 'gut' feeling, local knowledge and experience in determining appropriate livestock numbers despite the volume of science and theory directed at the issue. A similar conclusion was drawn by Holechek (1988) for rangelands in the USA. In contrast, Bartels *et al.* (1993) questions the validity of the carrying capacity concept in the communal rangelands in sub-Saharan Africa and recommends its application be stopped. In this paper the carrying capacity concept as it applies to Western range management, where livestock are mostly confined by fences and the land is owned or leased by individuals, is discussed. The paper describes an attempt to deliver a practical tool to groups within the community who make grazing capacity and stocking rate decisions.

In south-west Queensland, inappropriate livestock numbers and pressure from unmanaged herbivores (feral goats, kangaroos and rabbits) have reportedly caused pasture degradation and productivity losses in the region. Concern over the decline in agricultural productivity of the region has been expressed by a number of authors e.g., Ratcliffe (1937), Burrows and Beale (1969), Pressland (1976, 1984), Mills (1986), Warrego Graziers Association (1988), Mills *et* *al.* (1989), Miles (1989), Passmore and Brown (1992) and Anon. (1993). The processes and extent of degradation have been described by Burrows (1973), Brown (1981), Beale (1986), Mills (1986), Pressland and Cowan (1987), Mills *et al.* (1989), and Miles (1993). The most common forms of degradation reported by these authors are changes in herbaceous species composition and density and the lack of ground cover; accompanied by increases in soil erosion and woody shrub cover.

In response to these concerns a review of 'carrying capacities' and/or 'stocking rates' was suggested by the grazing industry (Warrego Graziers Association 1988), the Queensland Department of Primary Industries (Mills *et al.* 1989, Miles 1989) and the Queensland Department of Lands (Anon. 1993). From a land administration viewpoint the Department of Lands was concerned that its traditional rated carrying capacities generally represented an over-estimation of the ability of land types in the mulga region to sustainably carry stock in the long term (P.R. Tannock, pers. comm.). The majority of these ratings were based on subjective judgments from early settlement up to the 1940s and 1950s and were no longer considered appropriate by local land managers and administrators. In 1989 the Department of Lands reviewed the grazing capacities of properties in the Paroo and Bulloo shires of south-west Queensland based on benchmark properties and the land system mapping of Dawson (1974). For the Murweh and Quilpie shires an across the board reduction in rated carrying capacity was made (P.R. Tannock, pers. comm.). While these reviews generally reduced rated carrying capacities the process remained a subjective one.

The adjustment of livestock numbers is the main management option available to graziers in south-west Queensland. In an environment characterised by climatic and landscape variability it requires skill and experience to make such decisions. This experience can be complemented with sound and objective information regarding the grazing capacity of the resource. Several approaches are available for determining grazing capacity and appropriate stocking rates. Most are based on experience of stocking rates employed on '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 by graziers, land administrators and financiers.

Vallentine (1990) lists seven methods for determining grazing capacities and/or stocking rates.

- Initial stocking rate tables for various land and pasture types such as those reported for south-west Queensland by Mills and Purdie (1990).
- 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.
- Estimates of standing forage yield and conversion to stock numbers using appropriate levels of use for that forage, e.g. Ogwang (1992), Forge (1994).
- Percentage utilisation methods where estimates of forage utilisation are compared with appropriate levels of use for that forage.
- Forage comparison methods in which the grazing land under question is compared to a mental ideal or standard for that forage.
- Energy based methods requiring detailed measurements to match the energy content of forages to the requirements of grazing animals.
- Forage density methods requiring laborious estimates of forage density and quality to develop indices for appropriate stocking rates.

A number of these approaches require subjective judgement and some prior level of experience of the forages in question. To remove this limitation, a quantified approach to estimating grazing capacity, linking ecological principles, local knowledge and experience should prove valuable.

This paper describes the development of a model for objectively estimating 'safe' grazing capacities on individual properties. It is equivalent to the third method proposed by Vallentine (1990) except that it is based on calculated forage grown rather than standing forage yield. While not perfect, the model offers graziers and land administrators a tool to guide grazing capacity decisions at the individual property level.

Model development

A quantified approach to estimating 'safe' long term grazing capacities was developed based on primary productivity and simulation studies conducted in the region (Johnston unpublished). 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). As 'safe' grazing capacity is a strategic i.e. long-term (e.g. 20-30 years) estimate of stock numbers, it is seen to differ from a 'safe' 'stocking rate' which is a tactical i.e. short-term (seasonal or annual) calculation of 'safe' stock numbers.

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 material carried over from the previous 12 months and is thus distinct from average annual forage grown. Forage grown 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 paper. These estimates do not include carry-over material.

Thus the four factors which need to be determined are:

- 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.

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.

Intake

The amount of forage eaten (intake) was assumed to be 400 kg/DSE/year (McMeniman *et al.* 1986). The intake of leaf from the mulga tree (*Acacia aneura*) is also considered in this study and an intake of 600 kg/DSE/year is assumed to be required for maintenance of sheep consuming solely mulga.

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 forage grown.

Forage grown

A method for calculating average annual forage grown at any location in south-west Queensland based on rainfall use efficiencies (e.g. Le Houerou *et al.* 1988, Milchunas *et al.* 1994) for each land system was chosen (Johnston unpublished). The method attempted to account for:

- the variation in productivity between land systems;
- the impact of regional variation in rainfall on rainfall use efficiency;
- 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 correction factor accounting for the spatial distribution of woody species:

$$FG\ (kg) = PFG\ (kg) * WI * 1.168$$

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:

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

With pasture primary productivity measurements from only nine sites in south west Queensland, a lack of data limits our ability to confidently and quantitatively extrapolate rainfall use efficiencies over such a wide range and number of land systems recognised in the land system surveys. Our preliminary attempt to do so is as follows.

The SRUE for a land system expresses average annual forage grown (kg/ha) per unit of rainfall (mm). This was estimated for 190 land systems in south-west Queensland by linking simulation results from the forage production model GRASP (McKeon *et al.* 1990) to selected soil chemical and physical properties of each land system (soil pH, total phosphorus (TotP) and the proportion of fine sand (FS)) (Table 1):

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

Table 1. Site data from the Western Arid Region Land Use Studies (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)).

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

* From Johnston (unpublished).

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 regional variation in VPD:

$$VPDI = 22.997 / (190.024 + 0.2270*Latitude - 1.1068*Longitude)$$
$$(R^2=0.96\ n=13)$$

Forage grown is generally reduced by tree and shrub cover (e.g. Beale 1973 and Scanlan 1984). Based on a relationship described by I.F. Beale (unpublished) a woody index (WI) was calculated as:

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

Tree and shrub canopy foliage projected cover (FPC (%)) was measured at sites in each land system on each property. At each site 150 points were sampled in an area approximately 500 m in diameter using step points (Evans and Love 1957), and a periscope device similar to Buell and Cantlon (1950). At each point the presence or absence of a tree and/or a shrub canopy over either a point on the shoe (step point) or cross hairs of the periscope was noted. The distribution of the 40 sampling sites across a property was proportional to the areas of the land systems comprising each property.

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 assumed that only 5% of leaf fall was consumed by livestock (LUTIL) and an annual intake of 600 kg/DSE was required for maintenance (LI).

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

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

'Safe' level of forage utilisation

Three options were explored 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 (Johnston *et al.* 1996). As it complemented the first and second options it has been reported here.

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 2) 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 2).

Table 2. '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)

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 on 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 seven years, Table 2).

At the Gilruth Plains Mitchell grass site we believe 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. We believe that from the perspective of resource maintenance the heavier stocking treatment which equates to a calculated 23.4% utilisation was a safe treatment. If this is a correct interpretation of the findings of these trials, 'safe' utilisation levels (as defined in this paper) ranged from 15.5% to 26.6 % of average annual forage grown with an average of 22.4% across these trials.

Consensus data

A group consisting of two experienced graziers, two Department of Primary Industries staff and a Department of Lands officer (combined 139 years of experience in south-west Queensland), reached a consensus on their estimates of a 'safe' level of utilisation for each of the 15 land zones in south-west Queensland (Table 3). The range of 15% to 20% utilisation considered safe by consensus was similar to the range found for grazing trials (above). We investigated whether the utilisation levels for each land type may be related to the productivity of the land types. SRUE is a measure of site productivity. 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 (Fig. 1).

Table 3. 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

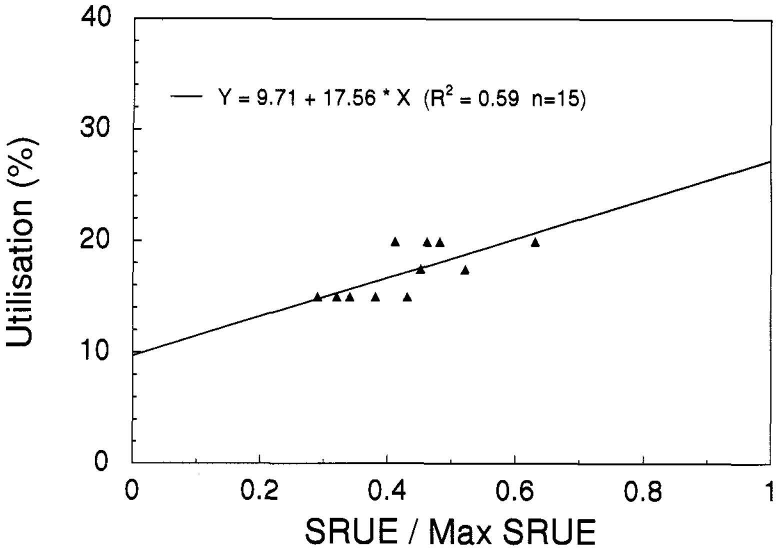

Fig. 1. The linear relationship between 'safe' levels of forage utilisation derived from consensus data and an index of land system fertility (ratio of land zone rainfall use efficiency to maximum standard rainfall use efficiency (SRUE)).

Selected benchmark properties and grazier experience

Three soundly managed 'benchmark' properties were selected (Fig. 2). These properties were considered by the Department of Lands and the grazing community 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 district.

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 we needed 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.

Thus with an estimate of average annual forage grown and average livestock numbers for each land system (Fig. 3a), utilisation was calculated (Fig. 3b). As the properties were considered to be in good condition, we assume here that the utilisation (SUTIL) of average annual forage grown (FG) on these properties and land systems were 'safe':

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

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

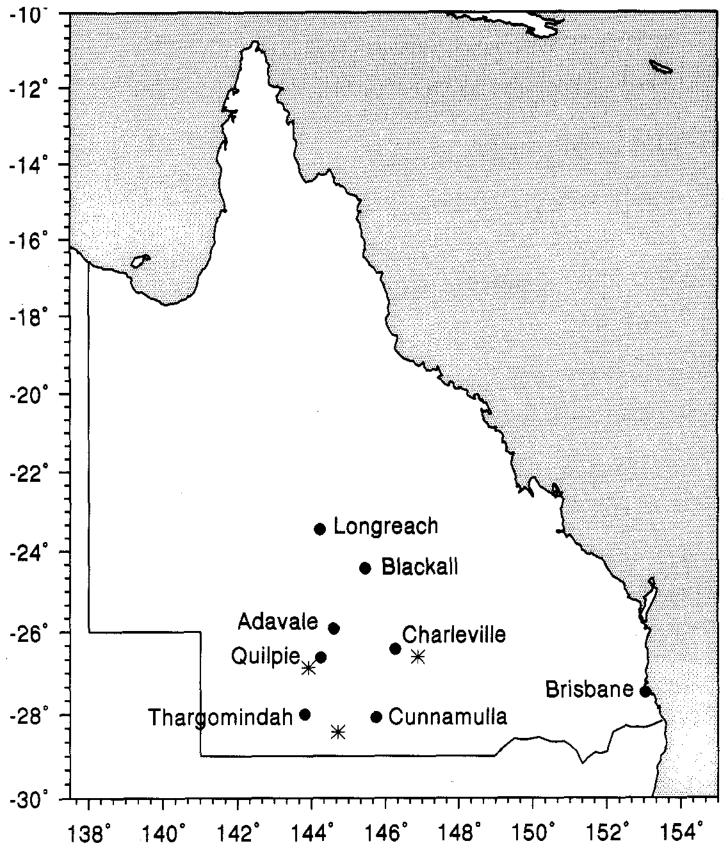

Fig. 2. Location of the three benchmark properties (*) used to estimate 'safe' levels of utilisation of estimated average annual forage grown in south-west Queensland.

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 between total intake (kg/ha) and average annual forage grown (kg/ha) (Fig. 3b). 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, we examined relationships between SRUE and utilisation. In this case a significant ($P<0.05$) negative relationship was found between utilisation and SRUE:

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

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 (Landsberg *et al.* 1992).

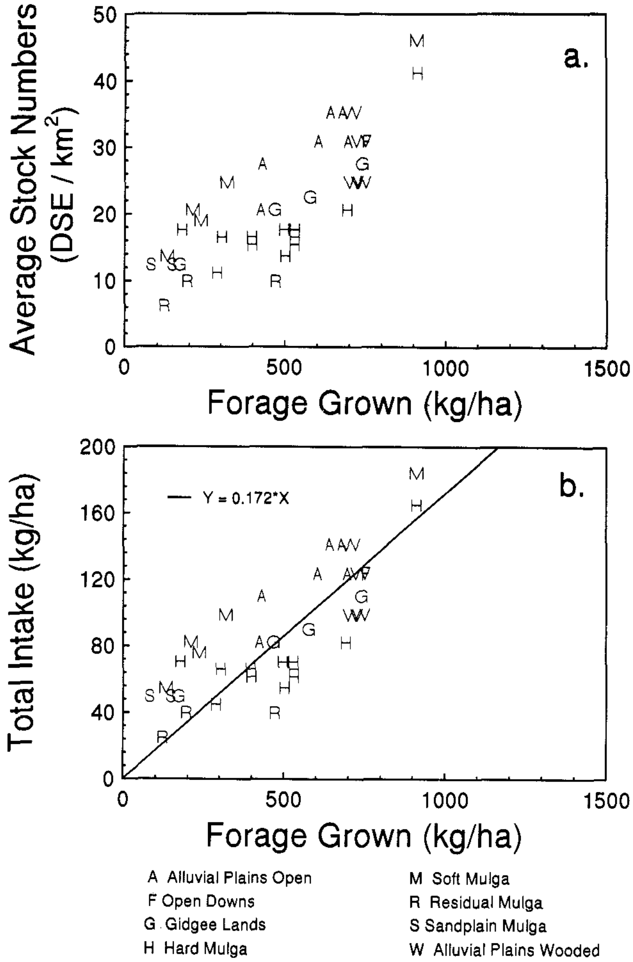

Fig. 3. The relationship between (a) average livestock numbers (DSE/km^2) and average annual forage grown (kg/ha) and (b) average annual total intake (kg/ha) and average annual forage grown (kg/ha) on the 38 land systems on the three benchmark properties used to estimate 'safe' levels of utilisation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

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 we decided to use the consensus data. This choice was made on the basis that this best represented a shared and, we assume, fair and balanced view. Rather than take an average utilisation value (17%) we hypothesised that a relationship exists 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 (Fig. 1). While this was true over the range of SRUE values examined we appreciate that the methodology described is likely to be used and evaluated beyond this range of fertility (SRUE). Given that such extrapolation is likely we believed it responsible 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 (Fig. 4) was:

$$SUTIL\ (\%) = (SRUE/Max\ SRUE)/(0.03340*(SRUE/Max\ SRUE) + 0.01022)$$
$(R^2=0.57\ n=15)$

For extremely infertile sites we have taken the view that grazing should only be conducted with very careful attention to stock numbers. Thus we have opted for a relationship which reduces safe utilisation to zero as SRUE approaches zero. We emphasise 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 our (the authors) attitude to risk.

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 (Fig. 4) reflects this assumption and, as such, provides a conservative safe utilisation level at high SRUE.

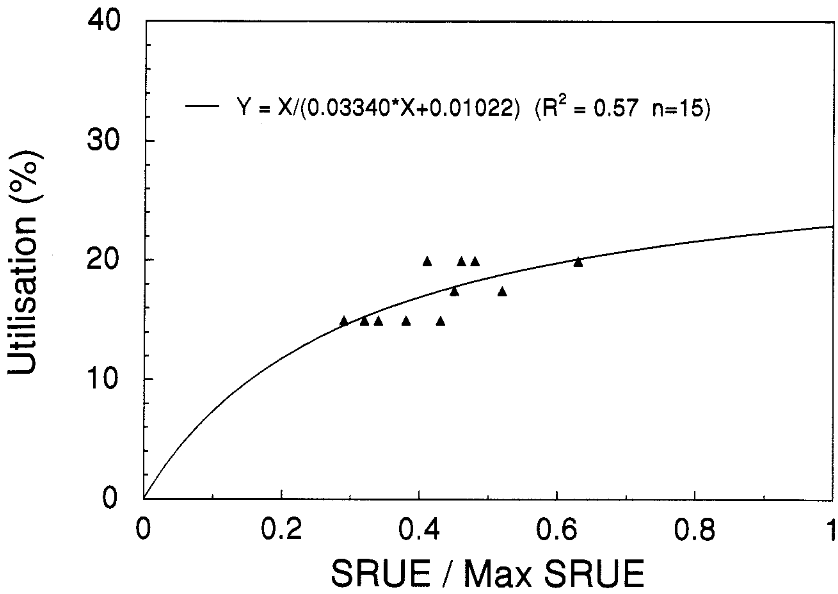

Fig. 4. The hypothesised curvilinear relationship between 'safe' levels of forage utilisation derived from consensus data and an index of land system fertility (ratio of land zone rainfall use efficiency to maximum standard rainfall use efficiency (SRUE)) used in the calculation of 'safe' grazing capacities for individual properties in south-west Queensland.

Sensitivity analysis

A sensitivity analysis was performed to determine how errors in coefficient estimation influenced the grazing capacity calculation for a land system. 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). The grazing capacity estimate was also sensitive to the first coefficient describing the woody index (1.008). For other coefficients and input values a ±10% change resulted in a less than 10% variation in the grazing capacity.

Discussion

Estimates of average annual forage grown based on 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 paper has developed links between science, 'benchmark' 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 that society places upon it (Walker 1995).

The methodology is repeatable and can be applied to any property in south-west Queensland or to other regions where rainfall is the major factor influencing forage production and appropriate data are available. The repeatability of the method enables it to be applied equally to individual properties to provide an individual 'safe' grazing capacity for that property. This alleviates the problems of inaccurate estimates of grazing capacities for properties when district average capacities are used. 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 (e.g. an increase in shrub density or the clearing of timber and introduction of improved pasture). Other factors such as the impact of soil loss or change in botanical condition could be included 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, improved estimates of appropriate property size could be examined. The determination of economic viability would then have a quantifiable basis. Definition and implementation of drought assistance policies could also be improved with use of the methodology. Instances where a disregard for resource capability and current seasonal conditions have induced an early 'drought' can 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 grazing land management.

The main limitations of the methodology presented here are (1) not accounting for spatial variability in resource use by grazing animals, (2) only accounting for the effects of tree and shrub cover as a measure of land condition impacting on the quantity of forage grown and (3) not accounting for the forage consumed by native and feral herbivores.

There is an active and on-going process of refining the methodology presented here. This involves field testing over an increasingly wide range of pastures and climates. To continue this evaluation requires commitment and support from researchers and funding bodies and the continued cooperation of the grazing community. At the current stage of development the methodology provides a formal framework for examining long term 'strategic' decisions regarding domestic livestock numbers. The methodology provides a repository for data from a variety of sources representing the combined experience of graziers, researchers and extension officers.

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