HOW LONG WILL SOIL RESOURCES LAST IN SEMI-ARID GRAZING SYSTEMS?

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Abstract
Sustainable management of grazing lands requires managers to maintain stocking rates at a level that maintains or improves the land condition. Erosion-productivity assessments were conducted by reducing the plant available water range and the nitrogen available, and assessing the effect against non-eroded growth. Simulation was undertaken using GRASP, a deterministic, point based, native pasture model developed for semi-arid and tropical grasslands. Model parameters were derived by combining grazier experience compared to the calculation of pasture growth for a given land type, tree density and pasture condition. Safe utilisation rates were highly correlated with annual pasture growth and represented 20-25% utilisation of annual growth. Erosion of 100 mm of soil was likely to reduce pasture productivity by 7-31%, depending on land type, with the less fertile land types most affected. If current safe stocking rates were maintained, then utilisation would increase by 12-58 %, thus placing even greater pressure on both pasture and soil condition.

Additional Keywords: erosion, productivity, grazing, pastures, carrying capacity.

Introduction

Sustainable management of grazing lands requires managers to maintain stocking rates at a level that maintains or improves the land condition. Periods of overgrazing (either due to drought or overstocking) result in a loss of land condition, represented in most cases by a decline in desirable perennial grasses and ground cover, leading to increased surface runoff and erosion. The implications of soil surface erosion for grazing land productivity are: loss of nutrients and organic matter in eroded materials; decrease in soil depth and plant available water capacity; and detrimental changes in soil structure. However, these processes operate over long time scales and their effects on production may not be immediately apparent, and thus difficult to quantify.

Many graziers in Queensland have adopted long-term sustainable stocking rates and can readily nominate ‘safe’ carrying capacities (SCC) for different land units (Hall *et al.,* 1998). ‘Safe’ carrying capacities achieve the multiple goals of minimising resource damage and providing greater stocking flexibility in terms of managing for dry and drought conditions. Previous studies across Queensland (Hall *et al.*, 1998; Johnston *et al.,* 2000) have shown land unit SCC was directly correlated with independently simulated pasture growth using a model (GRASP) of soil water and pasture dry matter flow to account for climate, soil and pasture attributes, and tree density. Thus SCC provides a base-line of recommended stocking practice for evaluating the impact of soil erosion on productivity through simulations of pasture growth. A simulation modelling approach is used to estimate the effects of erosion on pasture growth and carrying capacity of land types in the Western Downs of southern Queensland.

Materials and Methods

Description of the study area

The study area was defined by the location of the properties of producers in the Western Downs BeefPlan group (situated between Miles, Wandoan and Roma) who were surveyed to assess land type information and stocking rates. Rainfall is summer dominant with some winter rainfall, and simulations were based on the long term climate records of the township Wandoan obtained from the SILO national interpolated climate surfaces (Jeffrey *et al.,* 2001) using the latitude and longitude of 149.95 E and 26.11 S.

Land holder classification and carrying capacity calculation

Safe carrying capacity was derived directly from graziers knowledge and experience of safe carrying capacity, and compared to the calculation of pasture growth for a given land type, tree density and pasture condition (using the GRASP model). Accordingly landholders in the Western Downs classified land types on their properties in terms of vegetation communities and soil characteristics. Grazier-described land types were then matched against published land type descriptions from Perry (1968) and Harris *et al*. (1999). Landholders also rank the land types relative to each other in terms of:

- Pasture production
- Risk of soil erosion
- Long term stocking rate

This information was used to 'reality check' model outputs to ensure relative grass production, carrying capacity and runoff and soil loss are consistent with grazier observations. Nominated stocking rates for land types were then converted into animal intake, based on the assumption that an animal equivalent (AE) consumes 10 kg day^{-1}, whilst pastures are of good quality (Hall *et al*., 1998). Annual consumption estimates range from 2700 kg yr^{-1} (Hall *et al*., 1998) to 3650 kg yr^{-1} (Chilcott *et al*., 2003). Utilisation rate is defined as the amount eaten by cattle divided by the amount grown by applying the following equations to calculate utilisation and 'safe' stocking rate:

Utilisation (%) = Animal intake/pasture growth * 100%

'Safe' stocking rate = Forage Demand (per AE) / (Pasture Growth * Utilisation)

Modelling and analysis

Grass growth was determined using GRASP, a deterministic, point-based, native pasture model developed for semi-arid and tropical grasslands, as described in Littleboy and McKeon (1997). GRASP is an empirical model designed to simulate aspects of grass production and to predict soil water, pasture growth and animal intake. The two main components of the model are the water balance and pasture growth sub models. The soil water balance in GRASP simulates separately the processes of soil evaporation, pasture transpiration (Rickert and McKeon, 1982), tree transpiration (Scanlan and McKeon, 1993), run-off Scanlan *et al*. (1996), and through drainage. Rainfall is partitioned into runoff and infiltration using an empirical relationship derived from ground cover, daily rainfall, rainfall intensity and soil water deficit, which were derived from experimental measurements by Scanlan *et al*. (1996). Initially all growth parameters were derived from specific pasture communities obtained from datasets collected at 74 sites throughout Queensland (Day *et al*., 1997). Following the classification of land types by landholders, grazier-defined land types were ranked on the basis of soil texture and structure. Modelling parameter sets were then classified according to these groups, with no other modification made to parameters. Pasture growth (eg. transpiration use efficiency, maximum nitrogen uptake, regrowth rate and detachment rate) and soil parameters (eg. plant available water holding capacity, runoff parameters) were averaged from expert knowledge and past studies.

Erosion-productivity assessments were conducted by reducing the plant available water range and nitrogen available, and assessing the effect against non-eroded growth for a 100 year period between 1900 and 2000. A scalping simulation was performed in GRASP with soil depth reduced by 50, 100 and 150 mm compared against an uneroded profile. The plant available water content was reduced from the lower soil layers by the associated scalping depth. Nitrogen availability was reduced depending on the distribution of nitrogen for the soil type. The nitrogen distribution of the simulated land types was derived from Webb *et al*. (1982). Generally more nitrogen was found in the upper soil layers reducing with depth. Given this distribution of nitrogen, higher levels of soil erosion tended to have lesser effect on grass production. The resulting grass growth and carrying capacity were then re-calculated.

Results and Discussion

The responses from landholders surveys were compiled into 9 land types (Table 1), which were matched against soil survey information (Ian Heiner, *pers. comm.*). Land types as described by the landholder fit well with those described in the relevant land management manuals (Perry, 1968; Harris *et al*., 1999). In general, the most productive soils were considered those least prone to erosion, although land holders believed all soil could undergo erosion under poor management. For all land types specific pasture growth parameter sets were selected from sets described by Day *et al*. (1997), with no modification required to produce credible pasture production.

Grass growth simulations were conducted for all land types and the average pasture growth between 1900 and 2000 are presented in Table 2. Brigalow Belah Scrub had the highest average annual growth of 7250 kg ha^{-1} yr^{-1}, with Cypress Pine soils yielding 1200 kg ha^{-1} yr^{-1}. The simulated grass growth was consistent with the rankings of productivity from the producer survey.

Table 1. Land types descriptions of the Western Downs

Major Land Types on Property (common names)	Dominant Trees	Dominant Grass	Principal Profile Form	Australian Soil Classification	Erodibility			Fertility			Limitations of this soil							Rank grass growth*	Rank erosion risk**
			(Northcote, 1979)	(Isbell, 1996)	high	medium	low	high	medium	low	salinity	hard setting	nutrient deficient	rocky	poor water infiltration	sahllow depth	melon holes		
Brigalow Belah Scrub	Brigalow, Belah,	Qld Blue, Buffel, Bambatsi,	Ug 5.16	Grey Vertosol		**X**		X	**X**									**1**	**9**
(Softwood) Vine Scrub	Vine, Bottle tree, Belah, Brigalow,	Qld Blue, Buffel, Green Panic	Uf 6.34	Red Demosol		**x**		**X**										**2**	**5**
Flooded Alluvial Flats	Coolibah, Myall, Poplar Box,	Forest Blue, Pitted Blue, Black Spear,	Ug 5.17	Grey Vertosol		X	**X**	**X**										**3**	**8**
Flooded terraces	Poplar Box,	Forest Blue, Pitted Blue, Black Spear, Couch, Green Panic,	Dd 1.33	Grey brown Sodosol	X	X			**X**	X								**4**	**7**
Flooded Sandy Country	Apple tree, Wattle, Ironbark	Spear grass, Sand burr, Wiregrass,	Uc 1.21	Arenic Rudosol		**X**			**X**				**X**					**5**	**6**
Good Forest Country	Poplar Box, False Sandalwood, Belah,	Qld Blue, Pitted Blue, Forest Blue, Creeping blue	Ug 5.34	Brown Vertosol		**X**		X	**X**						**X**			**6**	**4**
Polar box woodlands	Poplar Box, False Sandalwood, Belah,	Qld Blue, Pitted Blue, Forest Blue	Dd 1.33	Brown Sodosol	**X**				X	**X**			**X**		**X**			**7**	**3**
Spotted Gum Bullock Forests	Spotted gum; Bull Oak	Wiregrass, Speargrass, Pitted Blue	Um 1.4	Leptic Rudosol	**X**		X			**X**		**X**	**X**	X	X			**8**	**2**
Cypress pine soils	Cypress Pine False Sandalwood, Bull Oak	Wiregrass, Speargrass,	Dy 5.42	Grey Sodosol	**X**					**X**		**X**	**X**	X	X			**9**	**1**

1 = grows most grass relative to other land types ** 1 = most at risk of soil erosion relative to the other landtypes

Brigalow (*Acacia harpophylla*); Belah (*Casuarina cristata*); Coolibah (*Eucalyptus microtheca*); Myall (*Acacia pendula*); Poplar Box (*Eucalyptus populnea*); Vine (*Ventilago viminalis*); Bottle tree (*Brachychiton australis*); Apple Tree (*Eucalyptus polysciada*); Wattle (*Acacia* sp.), False Sandlewood (*Eremophila mitchellii*); Spotted Gum (*Eucalyptus maculata*) Cypress Pine (*Callitris glaucophylla*); Bullock (*Allocasuarina luehmannii*); Qld Blue (*Dichanthium sericeum*); Buffel (*Cenchrus ciliaris*); Bambatsi (*Panicum coloratum*); Forest Blue (*Bothriochloa bladhii*); Pitted Blue (*Bothriochloa decipiens*); Black Spear (*Heteropogon contortus*); Couch (*Brachyachne convergens*); Green Panic (*Panicum maximum*); Wiregrass (*Aristida* sp.); Spear grass (*Aristida leptopoda*); Sand burr (*Cenchrus incertus*); Creeping Blue (*Bothriochloa insculpta*)

Table 2. Grass growth prediction, estimated stocking rates and utilisation rates for each land type

Major Land Types on Property (common names)	Ranking (from previous table)	Average Annual Growth (100 yrs)	Estimated Stocking Rate from survey information (AE ha^{-1})	Intake per ha (based on AE consuming 2700 kg yr^{-1})	Utilisation rate	Intake per ha (based on AE consuming 3650 kg yr^{-1})	Utilisation rate
Brigalow Belah Scrub	1	7250	1 to 2	1350	19%	1825	25%
Softwood Vine Scrub	2	5900	1 to 2.5	1080	18%	1460	25%
Flooded alluvial flats	3	6400	1 to 3	917	14%	1217	19%
Flooded terraces	4	4200	1 to 3.5	771	18%	1043	25%
Flooded Sandy country	5	3500	1 to 4	675	19%	912	26%
Good Forest Country	6	2400	1 to 5	540	23%	730	30%
Poplar Box woodlands	7	2150	1 to 6	450	21%	608	28%
Spotted gum Bullock forests	8	1400	1 to 10	270	19%	365	26%
Cypress Pine soils	9	1200	1 to 10	270	23%	365	31%
Average utilisation rate					19%		26%

Properties of landholders surveyed were all considered in 'benchmark' condition showing no signs of current or previous land degradation. These properties also had decision rules in place for destocking during drought periods when grass production was well below expected. Combining the experience of 'benchmark' landholders with the expected pasture production allow the calculation of carrying capacities. Thus for the selected properties in the Western Downs the average safe utilisation rate across all land types was 19 or 26% (depending on intake). Most land types have utilisation rates near the average, except flooded alluvial flats, where the stocking rate expectation of the landholders was lower than the simulated pasture growth suggested. A possible explanation is that this land type is used for finishing cattle for market and hence stocked more lightly.

Previously similar calculations of 'safe' stocking rate or carrying capacity have been made for three regions of Queensland. The Western Downs region safe utilisation rates using the lower estimate of annual consumption are similar than that predicted in the other regions: south-west Queensland, 14.5% (Johnston *et al.*, 1996); north-east Queensland, 19.3% (Scanlan *et al.*, 1994); and south-east Queensland, 22.0% (Day *et al.*, 1997b).

The effect of soil erosion on subsequent growth (Table 3) on the four most productive land types (those that originally grew greater than 4000 kg ha^{-1} yr^{-1}), was a reduction no greater than 13%, with minor increases in the utilisation rate (range of 12-15% increase) . These land types were both the most fertile (having more than 30kg N per year available for pasture growth). The effect of erosion on the five least productive land types (those that originally grew less than 4000 kg ha^{-1} yr^{-1}) was marked with reduction in pasture growth ranging between 21% and 37% for 150 mm soil loss, and always greater than the most productive sites. This resulted in large increases of the utilisation rate if eroded land types were grazed at the original level, with the worst being Poplar box woodlands with a utilisation rate of 45%, and all above 30% utilisation threshold where degradation of the grass basal area occurs (McKeon *et al.*, 1990). Average utilisations above these thresholds will lead to a high proportion of years (more than half) in which deterioration of grass and soil resources can occur (Scanlan *et al.*, 1994). These land types were the least fertile, with the annual maximum nitrogen available for pasture growth less than 21 kg ha^{-1} yr^{-1}.

Reduction in plant growth were greatest in years of above average rainfall (data not presented) suggesting the decline in soil fertility has the greatest affect on subsequent pasture growth. This supports the fact that the most fertile land types suffer lower reduction in pasture growth following erosion. An unfortunate implication for land management may be a concentration of effort to reduce erosion effects on land types where the consequences are obvious, but the return on any investment in mitigation or repairs will be lower.

Table 3. Effect of three different levels of erosion (50, 100 and 150 mm) on annual pasture growth and utilisation rate.

Major Land Types on Property (common names)	**Annual pasture growth following soil loss, with percent reduction in brackets**				**Utilisation rate following soil loss**			
	No soil loss	50 mm	100mm	150 mm	No soil loss	50 mm	100 mm	150 mm
Brigalow Belah Scrub	7250	7000 (4)	6600 (9)	6350 (13)	15	18	20	20
Softwood Vine Scrub	5900	5700 (3)	5500 (7)	5300 (10)	14	17	22	24
Flooded alluvial flats	6400	6200 (3)	6000 (7)	5750 (10)	25	26	28	31
Flooded terraces	4200	4050 (4)	3900 (8)	3700 (12)	28	31	34	36
Flooded Sandy country	3500	2800 (19)	2500 (27)	2350 (33)	31	44	47	51
Good Forest Country	2400	2200 (8)	2000 (17)	1800 (25)	28	31	36	41
Poplar Box woodlands	2150	1650 (24)	1450 (31)	1350 (37)	26	46	57	67
Spotted gum Bullock forests	1400	1200 (16)	1150 (20)	1050 (26)	27	41	42	47
Cypress Pine soils	1200	1050 (11)	1000 (14)	950 (21)	28	36	40	44
Average					26%	29%	32%	34%

Conclusions

The results show:

- That safe carrying capacity nominated by graziers was highly correlated with simulated average pasture growth, and represented 20-25% utilisation of average annual pasture growth;
- These safe utilisation rates are similar to previous studies in other regions of Queensland
- That the loss of 100 mm of soil was likely to lead to a 7-31% reduction in productivity of these pasture communities
- If current safe stocking rates were maintained, then utilisation would increase by 12-58 %, thus placing even greater pressure on both pasture and soil condition.

This study supported a simulation-based approach to extrapolate safe stocking rates derived from grazier experience to other locations with different climate and tree densities. This approach is currently being developed in the Grazing Land Management Education package in northern Australia (Chilcott *et al*., 2003) and hence provides a scientific/grazier knowledge basis for sustainable stocking rate strategies.

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References

Chilcott, C.R., Paton, C.J., Quirk, M.F. and McCallum B.S. (2003) Grazing Land Management Education Package Workshop Notes – Burnett, Meat and Livestock Australia Limited, Sydney.

Day, K.A., McKeon, G.M. and Carter J.O. (1997). Evaluating the risks of pasture and land degradation in native pasture in Queensland. Final report for Rural Industries and Research Development Corporation project DAQ124A.

Day, K.A., Scattini W.J. and Osborne J.C. (1997b). Extending carrying capacity calculations to the central Burnett region of Queensland, i*n* Droughtplan Working Paper No. 10, *ed. by* D.M. Stafford-Smith, Clewett, J.F., Moore, A.D., Mckeon, G.M. and Clark, R., CSIRO Alice Springs.

Hall, W.B., McKeon, G.M., Carter, J.O. and Day, K.A., Howden, S.M., Scanlan, J.C., Johnston, P.W. and Burrows, W.H. (1998). Climate Change and Queensland's grazing lands: II. An assessment of the impact on animal production from native pastures. *The Rangeland Journal*. 20: 177-205

Harris, P.S., Biggs A.J., and Coutts, W. (1999). Central Darling Downs land management manual : understanding and managing land in Wambo, Pittsworth, Rosalie, Millmerran, Jondaryan Shires, Dalby Town and Toowoomba City. Department of Natural Resources, Brisbane, Queensland.

Isbell, R.F. (1996). *The Australian soil classification*. CSIRO Publishing, Collingwood, Victoria.

Jeffrey S.J., J.O. Carter, K.B. Moodie and A.R. Beswick, 2001. Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software* 16, 309-330.

Johnston, P.W., McKeon, G.M., Buxton, R., Carter, J.O., Cobon, D.H., Day, K.A., Hall, W.B., and Scanlan, J.C. (2000). Managing Climatic Variability in Queensland's Grazing Lands – New approaches. *In Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems*, The Australian Experience. Edited by G.L. Hammer, N. Nicholls and C. Mitchell. pp. 197-226

Johnston, P.W., McKeon G.M., Day K.A., Mott J.J. and Hinton A.W. (1996). Objective "safe" grazing capacities for south-west Queensland Australia: Development of a model for individual properties. *The Rangeland Journal* 18 (2): 244-258.

Littleboy M. and McKeon G.M. (1997). Subroutine GRASP: Grass production model, Documentation of the Marcoola version of Subroutine GRASP. Appendix 2 of 'Evaluating the risks of pasture and land degradation in native pasture in Queensland'. Final Project Report for Rural Industries and Research Development Corporation project DAQ124A. Queensland Department of Natural Resources: Brisbane.

McKeon, G.M., Brook K.D., Carter J.O., Howden S.W., Johnston P.W., Scanlan J.C. and Scattini W.J. (1994). Modelling utilisation rates in the black speargrass zone of Queensland. *Proceedings of 8th Australian Rangelands Conference*, Katherine, 128-132.

McKeon, G.M. and Hall, W.B. (2002). Can Seasonal Climate Forecasting Prevent Land and Pasture Degradation of Australia's Grazing Lands? *QNR14 Technical Report for the Climate Variability in Agriculture Program*, Queensland Department of Natural Resources and Mines.

Northcote, K.H. (1979). *A factual key for the recognition of Australian soils, 4th Edition*. Rellim Technical Publication, Glenside, South Australia.

Perry, R.A. (1968). *Lands of the Dawson-Fitzroy area, Queensland*. CSIRO Land Research Series, 21.

Rickert, K.G. and McKeon G. M. (1982). Soil water balance model: WATSUP. *Proceedings of the Australian Society of Animal Production* 14, 198-200.

Scanlan, J.C. and McKeon G.M. (1993). Competitive effects of trees on pasture and a function of rainfall distribution and soil depth. In *Proceedings of the IVII International Grassland Congress*. p 2231-2232

Scanlan J.C., McKeon G.M., Day K.A., Mott J.J. and Hinton A.W. (1994). Estimating safe carrying capacities of extensive cattle-grazing properties within tropical, semi-arid woodlands of north-eastern Australia. *The Rangeland Journal*, 16, 64-76.

Scanlan, J.C., Pressland, A.J. and Myles, D.J. (1996). Runoff and soil movement on mid-slopes in north-east Queensland grazed woodlands. *Rangeland Journal* 18, 33-46.