State and transition models for rangelands. 4. Application of state and transition models to rangelands in northern Australia

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Abstract

Historically, there has been no widely used or accepted system for assessing the condition of rangelands in northern Australia. Consequently, there is a generally poor understanding of vegetation change and its consequences for long-term productivity and stability in the northern Australian pastoral industry. The state and transition approach to understanding vegetation dynamics has recently been put to use in the northern rangelands as a communication tool and for identifying gaps in knowledge in research. State and transition models are also being used in an integrated computer-based system to assess the spatial variability in the condition of grazing lands and then to evaluate the implications (environmental and economic) of the outcomes of alternative management scenarios. If state and transition models are to be used more effectively in the management of extensive grazing lands, the question of paddock heterogeneity and uneven grazing distribution needs to be addressed.

Introduction

Changes in botanical composition, productivity and land stability that occur in extensive grazing lands are commonly referred to as changes in range, veld or land condition. These changes are assumed to reflect the quality of those lands for livestock production. In the United States and South Africa, considerable effort has gone into developing objective methods for assessing range or veld condition, based on the range condition and trend concept of Dyksterhuis (1949). This model, based on climax theory (Clements 1916), categorises range condition into discrete classes, with movement between condition classes being completely reversible depending on management (i.e. grazing or resting). In these countries, range condition assessment based on climax theory has become entrenched in government policy (USDA SCS 1976; Mentis *et al.* 1989).

In contrast, in the semi-arid tropics of Australia, the concept of range condition has, until recently, received little attention from government agencies, research workers or land managers. There are 2 possible explanations for this situation, one philosophical and the other biological. Pasture agronomy, with emphasis on sowing introduced species and associated technologies, has historically dominated universities and government agencies in Australia. The discipline of rangeland management has been adopted only relatively recently by academic and other institutions in Australia, and even then it has largely been applied to the semi-arid and arid rangelands of southern and central Australia. In the semi-arid tropics, with the possible exception of the Kimberley region of northern Australia, issues relating to undesirable changes in native pasture composition, land stability, and long-term sustainability have become of public concern only in the last decade or so, as widespread degradation was not widely recognised and acknowledged until the late 1970s (e.g. DEHCD 1978; Woods 1983).

The absence of a particular range condition philosophy and objective range assessment criteria has negatively affected the management

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of rangelands. There is a generally poor understanding of vegetation change and its consequences for long-term productivity and stability in the northern Australian pastoral industry (e.g. Gardener *et al.* 1990). For example, key pasture species that are indicative of change, either desirable or undesirable, are not well recognised for many of the vegetation communities. Historically, most emphasis in management has been on raising cattle herd performance through improved husbandry and nutrition as, until stocking rates increased significantly across northern Australia through the 1960s and 1970s (Ash *et al.* 1992), land degradation was not perceived as a serious problem. Since then, attention has shifted to undesirable changes in vegetation and soil as a limitation on livestock production (Tothill and Gillies 1992). The introduction of a widely accepted system for assessing range condition, with a sound theoretical base to support it, would shift the balance of emphasis so that the economics of the cattle herd and the management of the underlying resource base are considered together.

One aspect of not having an established system for range assessment is that a model, relevant to the needs of management and based on sound ecological theory, is more likely to be adopted without prejudice. There is continuing debate in both North America and southern Africa as how best to integrate ideas from more recent non-equilibrium ecology and its expression in state and transition models (Westoby *et al.* 1989) with range condition concepts based on Clementsian climax theory. This task is made more difficult because both equilibrium and non-equilibrium models may operate in the same rangeland to different extents at different times (Walker 1988) i.e. no one model is appropriate in all situations. In northern Australia, making the decision to move from successional to non-equilibrium theory has not been necessary, although undeserved credit for making this paradigm shift has been given by Svejcar (1992), who stated that: "Australians have abandoned range condition and trend in favour of opportunistic management . . . the Australians have already suffered through their paradigm shift". The reality is that there was never an entrenched paradigm in Australia to shift from in the first place!

The question naturally arises as to the advantages of adopting the state and transition model approach to describe the processes involved in vegetation change in the tropical rangelands of northern Australia. Firstly, this approach provides a useful framework around which to organise information that is relevant to management and to focus on the key factors that drive vegetation change. It has the added advantage of highlighting the consequences of the interaction of climate (which is highly variable in northern Australia) and management actions for the sustainability of animal production. If states are distinguished in a way that is meaningful to land managers (e.g. plant functional groups that also have some relevance to animal productivity), the state and transition model immediately becomes a powerful tool for communicating the implications of vegetation change. Secondly, state and transition models are useful conceptual tools for research workers to identify gaps in knowledge. Thirdly, state and transition models, if adopted by land managers as an aid for decision making, can be used to highlight "management windows", where opportunities can be seized and hazards avoided. For example, a good wet season may provide the fuel to achieve a hot fire, thereby creating the opportunity to burn and greatly reduce woody weed seedling numbers. The following discussion examines these 3 advantages in more detail, with particular emphasis on the use of state and transition models in the tropical rangelands of northern Australia.

State and transition models for northern Australia

State and transition models are used in the semi-arid tropics at 2 levels. As qualitative conceptual models of vegetation change, they are being used for communication purposes and for identifying gaps in knowledge in research. The state and transition approach is also used as the basic modelling framework for vegetation change in an integrated computer-based system to assess the spatial variability in the state of grazing lands and then to evaluate the implications (environmental and economic) of the outcomes of alternative management scenarios (Bellamy *et al.* 1993b).

Conceptual models for communication and research

A simple state and transition model for the perennial grasslands of semi-arid northern Australia is presented in Figure 1. This model has 4 'herbaceous' and 3 'woody weed' states. The catalogue of transitions (Table 1) lists the type of events, either natural (e.g. climate) or management (e.g. grazing, burning), necessary to bring about the transition from one state to another. Although simple and not specific to any plant community, this model has proved to be a valuable communication tool, particularly with land managers, as they can generally identify their land with one or more of the 7 states and quickly grasp the concept of non-reversibility of certain transitions. When used in this way as an extension tool, fruitful and spirited discussion has generally ensued.

The model has also been used to identify gaps in knowledge and in formulating new research work. For example, how the economic productivity of land changes as desirable species are lost is an important question (e.g. State 1 ⟶

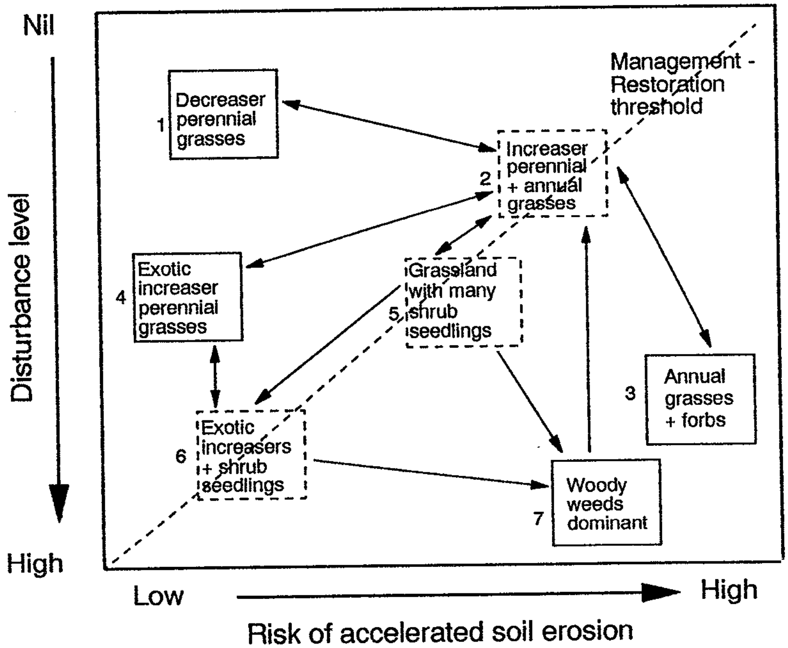

Figure 1. Generalised state and transition model for the tropical tallgrass lands of northern Australia.

Table 1. Catalogue of transitions for the tropical tallgrass lands of northern Australia. T(x,y) denotes the transition from State x to State y.

T(1,2)	Moderate to heavy utilisation, particularly during the early wet season. Hastened in poor seasons. In absence of fire, transition will occur in patch-grazed areas, even at overall low utilisation rates.
T(2,1)	Resting or much reduced level of utilisation. Hastened in good seasons. Use of fire will reverse transition brought about by patch grazing.
T(2,3)	Continued moderate to heavy grazing.
T(2,4)(5,6)	Moderate to heavy grazing with exotic grass seed-bank present.
T(4,2)	Unknown. Possibly use of fire with some species (e.g. *Bothriochloa pertusa*).
T(2,5)(4,6)	Woody weed seed-bank present. Absence of fire either for social reasons or due to lack of fuel as a result of over-utilisation.
T(5,2)(6,4)	Use of fire, particularly following good seasons when fuel loads are high.
T(5,7)(6,7)	Woody weed seedlings at a growth stage which will survive fire. Hastened in good seasons.
T(3,2)(7,2)	Transitions which are not possible through simple management actions. Mechanical and/or chemical intervention with possibly some use of fire required for (7,2). If perennial grasses are completely lost, seed input required for (3,2). Where soil is severely degraded, mechanical disturbance is required.

State 2 ⟶ State 3 in the model described in Figure 1), as the perceived decline in land condition may not be paralleled by a decline in animal production. An experiment, with sites at Charters Towers and Katherine, is demonstrating that, at low to moderate stocking rates, animal production from State 2 land can be higher than from State 1 land (Figure 2) (Ash *et al.* 1993). The challenge from these results is to demonstrate, using the state and transition model, that the short-term benefits of maintaining land in State 2 condition will be outweighed by the long-term cost of rehabilitation, should the transition to State 3 land be triggered.

Frameworks for integrated systems to evaluate management risks

Increasing emphasis is being placed on the development of state and transition models as aids in the management of specific rangeland areas. Their effectiveness will depend upon more accurate definition of the catalogue of states, the causes of transitions between states, and the probabilities of these transitions being effected, given specified environmental and management conditions. Through the accumulated knowledge of land managers, extension personnel, and research workers, in general, states of a particular rangeland type can be catalogued confidently. For example , a state and transition model for the Annual Sorghum plant community of the monsoonal tallgrass woodlands of the Northern Territory is shown in Figure 3. Examples of the definitions for selected transitions are shown in Table 2. The model was developed through an iterative knowledge acquisition process of workshops and other interactions with local and scientific "experts". This model is one of 5 different models developed in this way for the monsoonal tallgrass woodlands region, each of which relates to a dominant vegetation community-land type combination occurring in the region.

In complex pasture systems, particularly where shrub, woody weed and tree layers interact, state and transition models can become quite detailed and may even lose their value as a general

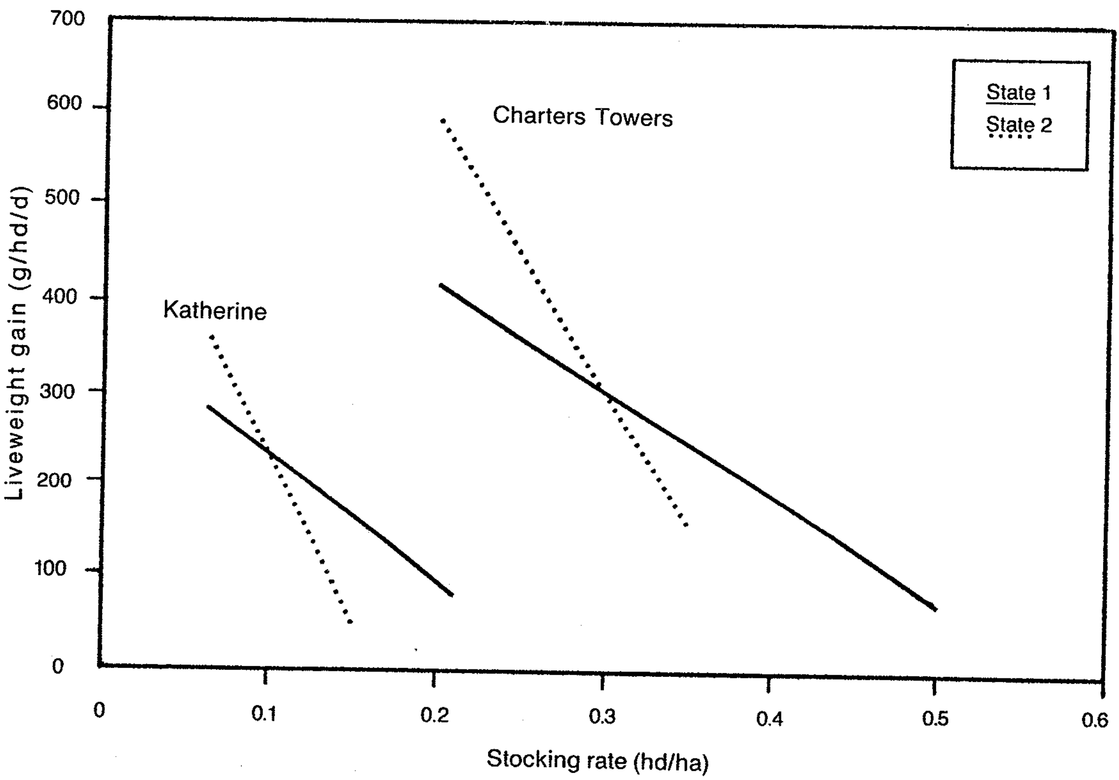

Figure 2. Relationship between stocking rate and animal production as influenced by land condition. (States 1 and 2 based on the model described in Figure 1).

communication tool. Estimation of the probabilities of individual transitions occurring can be achieved only through research and/or the detailed documentation of management activities and climatic sequences in a wide range of commercially grazed paddocks. Research to quantify these probabilities has commenced for some of the major community types of northern Australia. Once the probabilities have been determined, they can be presented to managers in the form of opportunities and hazards, which can identify "management windows" for achieving desired vegetation changes.

One major limitation in using state and transition models as aids to decision-making is that the smallest management unit in northern Australia, the paddock, is generally large (1000–50 000 ha) and heterogeneous, comprising a mosaic of plant community-land types. At any one time, it is likely that the various vegetation community-land types within a paddock will be in different states, that is a paddock will comprise a mosaic of different states each having: a different location with respect to, for example, water; a different potential attractiveness to grazing animals; and a different tolerance of disturbance. A management decision to bring about a desired transition in one plant community in a paddock may result in undesirable consequences for other plant communities in that paddock, or even overutilisation or underutilisation of the overall paddock.

A spatial decision support system (DSS), that utilises state and transition models as a conceptual framework for vegetation change, is being developed to provide an interactive tool to assist the user to assess the current condition of a grazing management unit (i.e. paddock or property), and to generate and evaluate the likely outcomes of alternative management strategies (Bellamy *et al.* 1993a; 1993b). The focus of this geographic information systems-based DSS is on the identification of management options that minimise the risk of degradation of the grazing land resource, and the improved management of the spatial variability of that resource. The value of such a system depends, however, on the confidence that can be placed in the knowledge base relating to the catalogue of states and to transitions, and also in the capacity to "model" in space and time the relationships between landscape units.

Conclusion

The state and transition model as a stand-alone product provides a useful conceptual model to organise information for a better understanding

Table 2. Examples of transitions for the annual sorghum areas of the monsoonal tallgrass woodlands, Northern Territory.

T(1,2)		**T(2,1)**	
Cause:	Lack of burning	Cause:	Unknown, possibly strategic burning in early dry after seed drop
Probability:	High	Probability:	Low
Time-frame:	10+ yr	Time-frame:	1+ yr
Confidence:	High	Confidence:	Low
T(1,3)		**T(3,1)**	
Cause:	Heavy utilisation with frequent burning	Cause:	Seed source for annuals available, no utilisation, favourable soil surface and establishment conditions
Probability:	Low	Probability:	High
Time-frame:	2 yr	Time-frame:	1–2 yr
Confidence:	Moderate	Confidence:	High
T(3,2)			
Cause:	Lack of burning, favourable establishment conditions		
Probability:	High		
Time-frame:	2–3 yr		
Confidence:	Moderate		

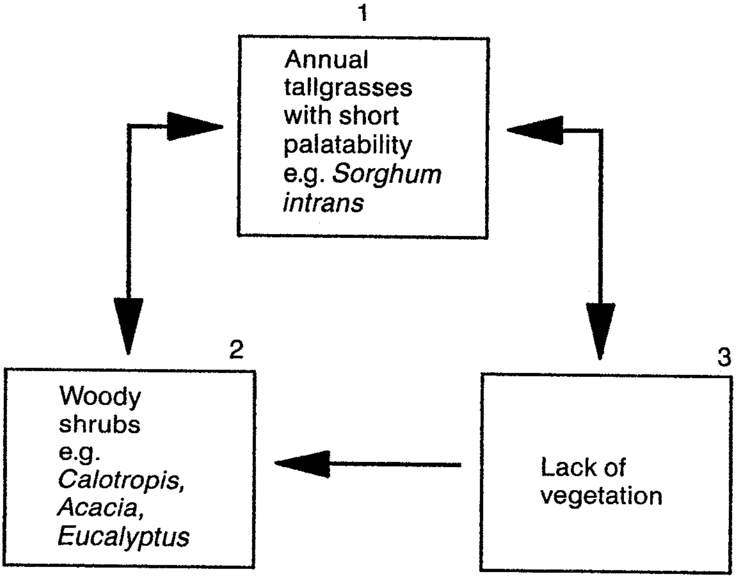

Figure 3. State and transition model for the annual sorghum environments of the monsoonal tallgrass woodlands, Northern Territory.

of vegetation change in rangelands and for communication of associated ideas. However, if state and transition models are to be used to support decision making in relation to the sustainable management of the extensive grazing lands in northern Australia, the question of paddock heterogeneity and uneven grazing distribution needs to be addressed effectively.

References

ASH, A.J., MCIVOR, J.G. and WINTER, W.H. (1992) Managing rangelands for production without degradation. In: Moffatt, I. and Webb, A. (eds) *Conservation and Development Issues in North Australia*. pp. 170–180. (NARU: Darwin).

ASH, A.J., MCIVOR, J.G. and BROWN, J.R. (1993) Land condition and overgrazing: a management paradox for the savannas of northern Australia. *Proceedings of the XVII International Grassland Congress, Palmerston North, 1993*. pp. 1930–1931.

BELLAMY, J.A., LOWES, D. and MACLEOD, N.D. (1993a) A decision support system for the sustainable use of Australian monsoonal tallgrass woodlands. *Proceedings of the XVII International Grassland Congress, Palmerston North, 1993*. pp. 1929–1930.

BELLAMY, J.A., LOWES, D. and MCLEOD, I.M. (1993b) A spatial decision support system for assessing the state of grazing lands. *Proceedings of the Northern Australian Remote Sensing and GIS Forum 1993, Darwin, N.T.* (University of NT: Darwin).

CLEMENTS, F.E. (1916) Plant succession: an analysis of the development of vegetation. *Carnegie Institute, Washington. Publication 242*. pp. 1–512.

DEPARTMENT OF ENVIRONMENT HOUSING AND COMMUNITY DEVELOPMENT (1978) *A Basis for Soil Conservation Policy in Australia*. Commonwealth and State Government Collaborative Soil Conservation Study 1975–77. Report 1. April 1978. (AGPS: Canberra).

DYKSTERHUIS, E.J. (1949) Condition and management of rangeland based on quantitative ecology. *Journal of Range Management*, **2**, 104–115.

GARDENER, C.J., MCIVOR, J.G. and WILLIAMS, J. (1990) Dry tropical rangelands: solving one problem and creating another. *Proceedings of the Ecological Society of Australia*, **16**, 279–286.

MENTIS, M.T., GROSSMAN, D., HARDY, M.B., O'CONNOR, T.G. and O'REAGAIN, P.J. (1989) Paradigm shifts in South African range science, management and administration. *South African Journal of Science*, **85**, 684–687.

SVEJCAR, T. (1992) Is the range concept compatible with ecosystems dynamics? *Proceedings of the Annual Meeting of the Society for Range Management, Spokane, Washington*. pp.19–20.

TOTHILL, J.C. and GILLIES, C.G. (1992) *The Pasture Lands of Northern Australia. Their condition, productivity and sustainability*. Occasional Publication No. 5. Tropical Grassland Society of Australia.

USDA SOIL CONSERVATION SERVICE (1976) *USDA SCS National Range Handbook*. (USDA Soil Conservation Service: Washington, DC).

WALKER, B.H. (1988) Autecology, synecology, climate and livestock as agents of rangeland dynamics. *Australian Rangeland Journal*, **10**, 69–75.

WESTOBY, M., WALKER, B.H. and NOY-MEIR, I. (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, **42**, 266–274.

WOODS, L.E. (1983) *Land Degradation in Australia*. (AGPS: Canberra).