Transitions across thresholds in Western Australian grazed rangelands

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Abstract

Thresholds and transitions between states are well-accepted components of the models of range dynamics. By definition, they represent a change from one state to another that is intransient and unlikely to reverse within an acceptable management timeframe or without significant management input. While more obvious transitions include those gross changes that occurred when livestock were introduced to Australian rangelands, transitions still occur under contemporary pastoralism. We used a state-wide monitoring data set to examine transitions that have occurred in the Western Australian pastoral rangelands over approximately the last 15 years. We found examples of transitions that were desirable as well as undesirable from a pastoral perspective. Transitions differed to the extent that they represented fundamental change to ecosystem dynamics or production potential as distinct from representing no more than substantial changes in species composition. This is important because once a threshold has been crossed, both managers and regulators need to adjust to the new reality, altering management to best address the new state and altering regulatory expectations so that condition is assessed within the context of the current state and its capacity to change.

Introduction

Over the last two decades, models of rangeland dynamics have emphasised non-equilibrium dynamics (Westoby et al. 1989; Friedel 1991; Stringham et al. 2003). There are many model variants, but most have a basis in state and transition models proposed by Westoby et al.

(1989). In short, ecosystems can be found in any one of a number of possible stable states. Transitions between states occur when thresholds are crossed. Some transitions are relatively simple to reverse, the majority are difficult and others impossible. Thresholds have become focal points within the state and transition framework because they differentiate the various states in which a site may be found (Briske et al. 2006).

Friedel (1991) defined a threshold as having two characteristics. First, it represents the boundary between two states such as grassland and shrub invaded grassland. Second, the shift across the boundary is not reversible on a practical time scale without substantial management intervention. A transition describes the process or trajectory whereby a site moves from one state to another. The threshold between two states is crossed at some point in the transition, typically at the point in which the transition becomes irreversible, or not easily so. The transition may occur rapidly, as in the case of changes brought about by fire in a fire-intolerant vegetation type, or slowly as in the case of changes brought about by woody weed invasion.

More recent literature, principally from the US, has further refined the concept of thresholds, defining a range of threshold types (Briske et al. 2006) and their application to state and transition modelling (Stringham et al. 2003; Bestelmeyer 2006; Briske et al. 2008). However in our experience, thresholds are easier to define conceptually than identify in the field and there is no simple recipe for determining a threshold or even deciding unequivocally what scale of difference represents a difference in state.

The most obvious transitions in Australian pastoral rangelands are those associated with the gross changes that occurred when livestock were first introduced to the rangelands or when drought subsequently interacted with high stock numbers to produce severe degradation episodes (McKeon et al. 2004). These thresholds included loss of topsoil and decline in vegetation condition (e.g. Wilcox and McKinnon, 1972; Payne et al. 1979) and the onset of severe woody weed thickening in both shrubland and grassland systems.

Almost all of the Western Australian pastoral rangelands have been grazed by domestic livestock since the late 19th and early 20th centuries, i.e. around 100 years or more. By and large, the gross changes that the introduction of livestock wrought occurred in the first few decades following pastoral expansion. However, as the literature suggests, a range of transitions, many of them more subtle and dominated by changes in species composition, are still possible under contemporary livestock grazing.

But what are the implications of crossing such a threshold, particularly when these are less drastic than the severe examples often used in the literature? And what are the implications for management, either from a regulatory viewpoint, or from the view of providing advice to graziers about appropriate grazing regimes? Given that transitions are typically difficult to reverse, managers and regulators will often need to adapt to the changed environment and assess production potential within the context of the new state. As a first step in addressing these questions we examined a state-wide vegetation monitoring data set from the Western Australian Rangeland Monitoring System (WARMS) to look for transitions over periods of up to 15 years.

Methods

Vegetation data from WARMS grassland sites in the Kimberley and WARMS shrubland sites from the Pilbara through to the Nullarbor were used to investigate transitions. These sites are used to represent the grazed rangelands of Western Australia. By definition they do not sample all vegetation everywhere and only represent ecosystems at the site scale (Watson et al. 2007) but they do provide a set of stratified examples for a range of vegetation types.

Grassland sites were installed between 1994 and 1996 and re-assessed every three years post installation. Shrubland sites were installed between 1994 and 1999 and re-assessed every five years. Only perennial vegetation was recorded. In general, seasonal quality was above average in the Kimberley over the past 15 years, with the majority of WARMS sites classified as having above average conditions. It is more difficult to summarise seasonal quality for the shrublands because the sites cover an area of approximately 500,000 km^2 but seasonal quality was generally very good throughout the area up until the early 2000s and temporally and spatially variable subsequently.

We examined data from Kimberley grassland sites for seven vegetation types (ribbon grass, arid short grass, black speargrass, bluegrass alluvial plains, soft spinifex, frontage grass and

Mitchell grass upland) representing 149 of 383 WARMS sites in that region. They were selected because they represented a significant proportion of the grazed vegetation types in the region, had reasonably well understood dynamics, and exhibited a capacity for transitional change. For the shrubland sites, we looked at all sites that were assessed three times, i.e. 919 sites.

We looked for persistent vegetation changes over time, i.e. across all three assessment periods for shrubland sites and all five assessment periods for grassland sites. We used standard WARMS frequency data (grassland sites) or count/density data (shrubland sites) for a given perennial species or species group. We ignored shorter-lived species, which have a natural tendency to fluctuate in numbers. We did not consider that increases or decreases per se were sufficient to be judged a transition when the species in question were already present in reasonable numbers or frequency prior to increase, or were still present in reasonable numbers or frequency following decrease. Additionally, we used our knowledge of species and community dynamics to include only those changes that were unlikely to be reversed at sub-decadal timescales and/or without substantial management input.

We acknowledge that determining transitions in this way is necessarily subjective. However, while conceptually clear, transitions don't lend themselves to simple quantitative definitions. The judgement of when a site has crossed a threshold is not as straightforward as the literature might suggest. For example distinct states might be recognised (Enneapogon dominance in Chrysopogon grassland or the reverse), but the actual threshold between these two states is less obvious.

Note that our examination of the WARMS record identifies those transitions that have occurred at the site scale and have run their course over the timeframes observed, or for which we judged the change would continue on the same trajectory. Many transition possibilities have long lag times (e.g. the recruitment of a long-lived shrub cohort) or occur off-site at the landscape scale (Pringle et al. 2006) and will take some time to be manifest as vegetation change at the site scale.

Results

On grassland sites, transitional change was often characterised by decline in desirable perennial grasses (from a grazing viewpoint) i.e. palatable, perennial and productive grasses, and their replacement by undesirable perennials and/or annuals (particularly *Aristida* species), less desirable but far more resilient perennial grasses (e.g. *Heteropogon contortus*) or a combination of both (Table 1). Transitions were not restricted to a single direction. For example, in the Mitchell grass uplands type, the desirable perennial grass *Chrysopogon fallax* increased on some sites and decreased on others. In some situations our experience suggests that if grazing pressure is reduced the changes in species frequency will start to reverse. However, in other cases, the increasing species, for example *Cenchrus ciliaris* in soft spinifex (*Triodia pungens*) vegetation type, or *H. contortus* in Ribbon Grass vegetation type, is particularly persistent, and will continue to dominate even if grazing pressure is removed entirely.

Threshold change incorporating significant increase in woody species was not common in any vegetation type in Kimberley grasslands. On WARMS sites, assessments of crown cover of woody species taller than 1m are made (Watson et al. 2007). Change in woody cover was extremely variable and temporally transient, but no sites appeared to have crossed a “woodiness threshold” over the period examined.

Table 1: Number of WARMS sites assessed in Kimberley grasslands, number and percentage of sites judged to have shown transitional change and examples of species change.

Vegetation type (and dominant species)	Sites assessed	Sites on which a transition was observed	Examples of change
Arid short grass (*Enneapogon polyphyllus*)	12	3 (25%)	Decrease: *Aristida* species, *Sorghum plumosum*. Increase: *Chrysopogon fallax*, *Sehima nervosum* and *Triodia intermedia*.
Black speargrass (*Heteropogon contortus*)	4	1 (25%)	Decrease: *S. plumosum*, *C. fallax.* Increase: *Aristida inaequiglumis*, *S. nervosum*, *Heteropogon contortus*
Bluegrass alluvial plains (*Dicanthium fecundum*)	10	3 (30%)	Decrease: C*. fallax, Dicanthium fecundum* Increase: *H. contortus, S. plumosum*
Soft spinifex (*Triodia pungens*)	11	2 (18%)	Decrease: *Triodia pungens* Increase: *Cenchrus ciliaris*
Frontage grass (various)	23	4 (17%)	Decrease: *Whiteochloa airoides*, *Eragrostis falcata* Increase: *C. fallax, Triodia pungens, D. fecundum, Eriachne obtusa*
Mitchell grass uplands (*Astrebla elymoides*)	28	3 (11%)	Decrease: *Enneapogon polyphyllus, Aristida hygrometrica, Sorghum timorense, C. fallax* Increase: *H. contortus, C. fallax, Panicum decompositum, S. plumosum*
Ribbon grass (*Chrysopogon fallax*)	61	9 (15%)	Decrease: *A. hygrometrica, A. inaequiglumis, E. polyphyllus, E. obtusa,* Increase: *C. fallax, H. contortus, Triodia intermedia, Cenchrus setigerus, S. nervosum, A. inaequiglumis, Eulalia aurea*
Total	149	25 (17%)	

Of the 919 shrubland sites assessed once in each of three assessment periods, transitions were observed on 10 sites, or 1% (Table 2). On a further 30 sites (3%) we observed change suggestive of a transition that was either of insufficient magnitude to be reliably classified as a transition, or was not far enough advanced to be confident that the change was intransient.

The most common type of transition was associated with large increases in tall shrubs or trees, particularly *Acacia victoriae* but also *A. aneura* and *A. xiphophylla*. Thickening due to low shrubs, mostly various *Eremophila* species but also *Senna* species, was also observed.

The number of *A. papyrocarpa* individuals was observed to increase markedly on nine sites. We hesitate to label this a transition because it is arguable whether a bladder saltbush or pearl bluebush community with low density of *A. papyrocarpa* is in a different state to one with high density. However, since these trees bring a tall structural element to what is otherwise a low shrubland, and since the loss of *A. papyrocarpa* and/or lack of recruitment has traditionally been a cause for concern, we considered it reasonable to consider the changes as state changes.

Table 2: Number of WARMS shrubland sites assessed, number of sites judged to have shown transitional change, number of sites where transitional change is suggested (in parentheses) and examples of species change.

Vegetation type	# of sites	# of sites transition observed	Examples of change
Acacia mixed shrublands	10	0 (1)	Increase: *Eremophila forrestii*
Bladder saltbush	72	0 (2)	Increase: *Acacia papyrocarpa*
Currant bush mixed	14	0 (0)	n/a
Gascoyne bluebush	34	0 (1)	Increase: *Acacia victoriae*
Hardpan mulga shrub	212	0 (8)	Increase: *Acacia aneura*, several *Eremophila* species
Mixed halophytic	128	0 (3)	Decrease: *Atriplex amnicola*, *E.maculata* Increase: *Maireana pyramidata*
Other	25	1 (0)	Increase: *Acacia sclerosperma, Acacia tetragonophylla*
Pearl bluebush	97	0 (7)	Increase*: A. papyrocarpa*
Riverine mixed	10	0 (0)	n/a
Sago bush	64	1 (2)	Decrease*: Rhagodia eremea* Increase*: A. aneura, A. victoriae, M. pyramidata*
Sandplain –Acacia / mallee / pine shrub	15	0 (1)	Increase: *A. aneura, Eremophila granitica, Olearia pimeleoides*
Sandy granite Acacia shrub	21	0 (0)	n/a
Silver saltbush	25	3 (0)	Decrease: *Rhagodia eremea* Increase: *A. victoriae*
Stony – Acacia / Senna / Eremophila / Ptilotus	69	1 (1)	Increase: *A. tetragonophylla, E. cuneifolia, E. fraserii, S. artemisioides subsp. helmsii*
Stony mixed chenopod	47	3 (3)	Decrease: *M. pyramidata* *Increase: A. tetragonophylla, A. victoriae, A. xiphophylla, E. cuneifolia, H. preissei, S. artemisioides subsp. x sturtii*
Tussock grass – miscellaneous	5	1 (1)	Decrease: *Eremophila forrestii, Stylobasium spathulatum* Increase: *A. victoriae*
Wandarrie grass	71	0 (0)	n/a
TOTAL	919	10 (30)	

Discussion

We consider this a preliminary exercise and acknowledge that our approach to judging change of state is unsophisticated. However, it is clear that thresholds continue to be crossed, from one state to another, in the grazed rangelands of Western Australia. Transitions appear to be more common in the northern grasslands than in the southern shrublands, but only a restricted grasslands data set was examined and some vegetation types, particularly those dominated by hard spinifex would rarely change over century timescales. Not all transitions could be considered negative, while the “degree of difficulty” in crossing the threshold and potentially reversing the change varied with vegetation type. We have addressed transitions at the scale of individual sites, principally because of the data source available to us. However, it is clear that thresholds are expressed across multiple scales at landscape and even regional scales (Briske et al. 2006) and that management responses are invariably executed at paddock or property scales.

What does this mean for management and for regulation? First, where a persistent change (at least within what could be termed a management timeframe) has occurred in the state of the vegetation, assessment of the condition of the rangeland, its production potential and future management scenarios must be interpreted within this new context. Changes in species composition, even substantial, do not necessarily signify a decline in ecosystem function (Hibbard et al. 2003) or production potential (Norris et al. 2001). Managers need to accept the new state as reality for the foreseeable future and will need to adjust their operations to best manage the new vegetation community. Second, regulators cannot expect managers immediately, if at all, to enact a management regime that will return the community to its previous state. Both condition assessment and management must be predicated on the fact that a threshold has been crossed and that reversal of change may be difficult.

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References

Bestelmeyer, B.T. (2006) Threshold concepts and their use in rangeland management and restoration: the good, the bad and the insidious. *Restoration Ecology* **14**, 325-329.

Briske, D. D., Fuhlendorf, S.D. and Smiens, F.E. (2006) A unified framework for assessment and application of ecological thresholds. *Rangeland Ecology and Management* **59**, 225-236.

Briske, D. D., Bestelmeyer, B.T., Stringham, T.K. and Shaver, P.L. (2008) Recommendations for development of resilience-based State-and-Transition Models. *Rangeland Ecology and Management* **61**, 359-367.

Friedel, M.H. (1991) Range condition assessment and the concept of thresholds: a viewpoint. *Journal of Range Management* **44**, 422-426.

Hibbard, K. A., Schimel, D.S., Archer, S., Ojima, D.S. and Parton, W. (2003) Grassland to woodland transitions: integrating changes in landscape structure and biogeochemistry. *Ecological Applications* **13**, 911–926.

McKeon, G.M., Hall, W. Henry, B.H., Stone, G. and Watson, I.W. (Eds) (2004) Pasture degradation and recovery in Australia's rangelands. *Learning from history*. Queensland Department of Natural Resources, Mines and Energy, Brisbane, Australia, 256 pp.

Norris, M. D., Blair, J.M., Johnson, L. C. and R. B. McKane. (2001) Assessing changes in biomass, productivity, and C and N stores following Juniperus virginiana forest expansion into tallgrass prairie. *Canadian Journal of Forest Research* **31**, 1940–1946.

Payne, A.L., Kubicki, A., Wilcox, D.G. and Short, L.C. (1979) A report on the erosion and range condition in the west Kimberley area of Western Australia. *Technical Bulletin No. 42*. Department of Agriculture of Western Australia.

Pringle, H.J.R., Watson, I.W. and Tinley, K.L. (2006) Rangeland improvement, or ongoing degradation - reconciling apparent contradictions from the arid rangelands of Western Australia. *Landscape Ecology* **21**, 1267-1279.

Stringham, T.K., Krueger, W.C. and Shaver, P.L. (2003) State and transition modelling: and ecological process approach. *Journal of Range Management* **56**, 106-113.

Watson, I.W., Novelly, P. Thomas, P.W.E (2007) Monitoring changes in pastoral rangelands – the Western Australian Rangeland Monitoring System (WARMS). *The Rangeland Journal* **29**, 191-205.

Westoby, M., Walker, B.H. and Noy-Meir, I. (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266-274.

Wilcox, D.G. and McKinnon, E.A. (1972) A report on the condition of the Gascoyne River catchment. Western Australian Department of Agriculture Technical Bulletin No. 2.

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