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Transitions across thresholds of vegetation states in the grazed rangelands of Western Australia

I. W. Watson[A,C] *and P. E. Novelly*[B]

[A]CSIRO Ecosystem Sciences, PMB Aitkenvale, Qld 4814, Australia.
[B]Department of Agriculture and Food Western Australia, South Perth, WA 6151, Australia.
[C]Corresponding author. Email: ian.watson@csiro.au

Abstract. Thresholds and transitions between vegetation states are accepted components of models of rangeland dynamics. By definition, transitions represent changes from one state to another that are enduring, and are unlikely to be reversed within an acceptable management time frame or without significant inputs of management. A monitoring dataset, containing 306 grassland sites and 919 shrubland sites, was used to identify transitions that have occurred in the pastoral rangelands of Western Australia between 1993 and 2010. The grassland sites were assessed on five occasions and the shrubland sites on three occasions. Transition between vegetation states was assessed using the expert knowledge of the authors. A total of 11% of the grassland sites and 1% of the shrubland sites were determined to have undergone a transition, negative as well as positive from a pastoral perspective, over the sampling period. It is argued that, once a transition has occurred, both pastoral managers and government regulators need to adjust to the new conditions, altering management to best address the new state and altering regulatory expectations so that range condition is assessed within the context of the current state and its further capacity to change.

Additional keywords: alternative states, range monitoring, state and transition, vegetation dynamics.

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Introduction

Over the last two decades, models of rangeland vegetation 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, at any time a given ecosystem can be found in any one of several possible stable states. At some stage along the transition between two states, a threshold is crossed.

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 inputs of management. 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 stage during the transition, typically when the changes are difficult to reverse. 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 an invasion of woody weeds. Some transitions reverse, following relatively straight forward managerial change, but require long time frames and/or sequences of favourable seasons. The majority of transitions, however, are ecologically and/or managerially difficult to reverse and others impossible due to a fundamental change such as soil loss. 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) and, thereby, provide a defined status around which management decisions can be made.

More recent literature, principally from the United States, 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). In the experience of the authors in Australia, thresholds are easier to define conceptually than to identify in the field, and there is no simple recipe for determining a threshold or even deciding unequivocally what scale of difference in vegetation composition and density represents a difference in state. Typically, only qualitative descriptions of each state are provided in the literature and little attempt has been made to define the stage at which the transition between them occurs. More quantitative descriptions of states or probabilities of transition are rare (but see Scanlan 1994) while Friedel (1991, see fig. 4 therein) provided precise suggestions, in terms of the density of trees, for the stage at which thresholds are crossed between grass-dominated, tree-dominated and eroded states in a South African savanna site.

Increasingly, there is recognition that these non-equilibrium models need to be developed, communicated and used in a spatial, rather than point-scale, context (Bestelmeyer *et al*. 2011) although most state and transition models are still developed based on changes that might be observed at the scale of an individual monitoring site or equivalent.

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 (Stafford Smith *et al*. 2007). These transitions often included soil degradation and a decline in the condition of the vegetation (e.g. Wilcox and McKinnon 1972; Payne *et al*. 1979) such as the loss of productive perennial species or the onset of severe woody-weed thickening in both shrubland and grassland systems (e.g. Noble 1997).

Almost all Western Australian pastoral rangelands have been grazed by domestic livestock for 100 years or more since the late 19th and early 20th centuries, By and large, the gross changes that the introduction of livestock wrought occurred in the first few decades following pastoral expansion. However, a range of transitions, many of them more subtle and dominated by changes in species composition rather than gross degradation, are still possible under contemporary livestock grazing (Jones and Burrows 1994; McIvor and Scanlan 1994).

It is common to recognise different states from observing rangeland vegetation. Fence-line contrasts and the effect of distance from water, especially following the addition of new watering points, provide obvious examples. However, it is less common to observe transitions between states while they are in-train, and rarer still to be able to observe the stage at which a threshold is crossed. Moreover, many transitions are both interesting and notable, and they tend to be recognised in an opportunistic way so that a biased view may be formed as to the frequency with which transitions occur. The aim of this paper was to determine how commonly transitions occurred across a broad area of the rangelands, at a large number of representative locations over periods of 8–13 years (shrubland sites) or 12–15 years (grassland sites).

Further, the implications of crossing a threshold, particularly when these are less drastic than those representing severe degradation, were considered. The implications for management, either from a regulatory viewpoint or from the view of providing advice to graziers about appropriate grazing regimes, were also considered. Given that transitions are typically difficult to reverse, managers and land administrators will often need to adapt to the changed environment and assess production potential within the context of the new state, notwithstanding the aim of avoiding adverse transitions in the first place.

As a first step in addressing these questions a vegetation monitoring dataset from the Western Australian Rangeland Monitoring System (WARMS: Watson *et al*. 2007*a*), which covered most of the rangelands used for commercial livestock grazing in Western Australia, was examined to find 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 (Watson *et al*. 2007*a*, see fig. 1a therein) 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 or vegetation types everywhere and only represent ecosystems at the scale of the site (Watson *et al*. 2007*a*) but they do provide a set of stratified examples for a range of vegetation types. The WARMS sites are part of a pastoral monitoring system and are subject to prevailing environmental conditions, commercial management actions and their interactions. Sites were thus subject to the commercial pastoral regime operating in the paddock in which they were situated. During the sampling period there was no attempt to experimentally manipulate any of the sites, nor any of the drivers, such as fire or grazing, that may trigger a transition. Some grassland sites, however, were excluded as fire had prevented data collection on some occasions (see below). A small number of sites were installed on pastoral leases subsequently acquired for conservation by the state of Western Australia (Watson *et al*. 2007*a*) and were not subject to commercial grazing management for the latter part of the sampling period.

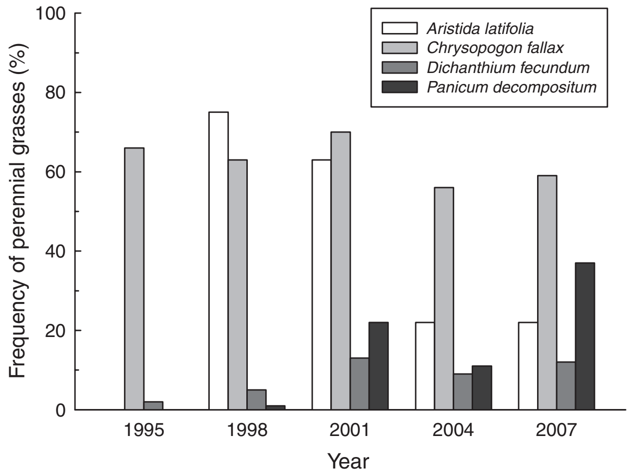

Fig. 1. Typical change in frequency of perennial grasses of the Mitchell grass alluvial plains vegetation type in the Kimberley. While there was considerable change in the frequency of perennial grasses, this site was not judged to have made a transition between states. Note that an additional two species, *Aristida inaequiglumis* and *Astrebla pectinata*, were also present on the site but have not been shown in order to improve presentation. They had maximum frequencies of one.

Kimberley grassland sites were installed between 1994 and 1996 and were re-assessed every 3 years, with a few sites outside this strict schedule. Shrubland sites were installed between 1993 and 1999 and, while the majority of reassessment intervals were between 4.5 and 5.5 years, some intervals were as short as nearly 4 years and others were as long as just over 8 years. Perennial species were recorded at all sites and, in the grasslands, some biennial and annual vegetation was also recorded. In general, the majority of WARMS sites in the Kimberley grasslands were classified as having above average seasonal conditions (i.e. amount, timing and seasonality of rainfall between site assessments) over the 15-year sampling period. It is more difficult to summarise seasonal conditions for the shrublands because the sites cover ~500 000 km^2 and, over this area, the rainfall was variable. Seasonal conditions were generally very good throughout the shrublands until the early 2000s (Watson *et al*. 2007*b*) and temporally and spatially variable thereafter.

Changes in the standard WARMS frequency data (grassland sites) or count/density data (shrubland sites) for a given species or species group were used as an indication of vegetation change (Watson *et al*. 2007*a*). Note that frequency is assessed as presence or absence in quadrats so that plant density may change while species composition remains the same. Data from 306 Kimberley grassland sites, which had been re-assessed either four or five times since installation, were examined for the existence of transitions. A further 77 sites were not assessed because of an incomplete data record, for example being inaccessible or having been recently burnt at a defined sampling date. For the shrublands, all sites in the WARMS dataset that had been assessed three times were examined, giving 919 sites.

Standard WARMS vegetation types were used. Grassland and shrubland provided the first level of differentiation with the next level being very broad categories of vegetation type (e.g. Mitchell grass, bluebush), which were used for the initial WARMS site stratification (see Watson *et al*. 2007*a*). The final classification, used in this paper, was based on the multivariate analysis of Duckett (1997, 2001) with subsequent amendment to more closely match the vegetation types used by the Department of Agriculture and Food, Western Australia (DAFWA) as given by Payne and Schoknecht (2011) for Kimberley vegetation types and Payne *et al*. (1982) (and subsequent DAFWA resource inventories in other regions) for shrubland sites.

Deciding what conditions represent discrete changes and deciding when a threshold has been crossed is imprecise for two reasons. First, states are typically user-defined (Whalley 1994) and tend to be recognised only when the ecosystem changes have societal significance (Bestelmeyer *et al*. 2011). Second, detailed studies of individual vegetation types over a long period of time are required to properly understand and then define the full range of state changes. Bestelmeyer *et al*. (2011) noted that state and transition models are typically developed using a range of techniques including expert knowledge, space for time substitutions and controlled experiments. In this study, the authors used their knowledge of shrublands (Watson) and grasslands (Novelly) gained from exclosures, grazing experiments and long-term monitoring, as well as information contained in resource inventories (e.g. Stewart *et al*. 1970; Payne *et al*. 1982), to determine a change in state. Prior knowledge of the existence of alternative states for a given vegetation type was used as the primary determinant as to whether a transition had occurred.

The following criteria were used to determine that a transition had occurred. First, the change in the relative abundance of species had to be substantial, and result in either the dominance of one or more species that had not been recorded initially or had been recorded in only low numbers, and/or the decline to very low numbers or the disappearance of a species that had been dominant initially. The occurrence of some individuals in both the initial and final state did not negate a transition having occurred, a phenomenon also recognised in discussions on climax theory (Whittaker 1953). Second, the change had to exhibit and maintain a defined trend across both assessment periods in the case of shrubland sites and at least four assessment periods for grassland sites. Third, the change had to represent a significant change in characteristics such as structure and function, productivity and pastoral value of the vegetation community at the site. Fourth, the change had to be of sufficient magnitude that it was judged by the authors to be irreversible within practical time frames (if ever) or without significant managerial input.

Increases or decreases in species number or frequency *per se* were insufficient to be judged a transition in situations where the species in question were already present in reasonable numbers or frequency before increase, and were still present in reasonable numbers or frequency following decrease. Only those changes that were unlikely to be reversed at sub-decadal timescales and/or without substantial management input were included. Shrubland sites were also identified where change suggestive of a transition was observed but 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 persistent. This additional identification of possible transitions was made because of the lower rates of change in demographic attributes among shrubland species compared with grassland species, and because there were only three assessments for these sites.

Determining transitions in this way is subjective. While conceptually clear, transitions do not lend themselves to simple quantitative definitions without intensive research. 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 (biennial *Enneapogon*[1] dominance in perennial *Chrysopogon* grassland or the reverse) but the actual threshold between these two states (i.e. from a perennial-dominated grassland to a biennial-dominated grassland) is less obvious.

Note that the examination of the WARMS record identified only those transitions that occurred at the site scale and which had run their course over the time frames observed, or for which it was 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 through to maturity) 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

Of the 306 grassland sites assessed, 34 (11%) were determined as having undergone a transition over the sampling period (Table 1). Transitional change was often characterised by a decline in desirable perennial grasses (from a grazing viewpoint) i.e. preferred, perennial and productive grasses, such as *Chrysopogon fallax* (Ribbon grass), and their replacement either by undesirable (in a pastoralism sense) perennials and/or annuals (particularly *Aristida* species), less desirable but far more resilient perennial grasses (e.g. *Heteropogon contortus*) or a combination of the two (an example is shown in Table 2). In some

[1]Botanical nomenclature is that used by the Western Australian herbarium as accessed through the Western Australian Department of Conservation and Environment's FloraBase website (http://florabase.dec.wa.gov.au/, accessed 21 June 2012).

Table 1. Number and vegetation type of Western Australian Rangeland Monitoring System sites assessed in Kimberley grasslands as well as number (and percent) of sites judged to have shown a change in state

Vegetation type (and dominant species)	Sites assessed	Sites on which a transition was observed
Arid short grass (*Enneapogon polyphyllus*)	12	2 (17%)
Black speargrass (*Heteropogon contortus*)	4	1 (25%)
Bluegrass alluvial plains (*Dicanthium fecundum*)	10	3 (30%)
Buffel grass (*Cenchrus ciliaris*, *Cenchrus setiger*)	12	0
Curly spinifex – Annual sorghum hill (*Triodia bitextura*, *Sorghum* spp.)	3	0
Curly spinifex plains (*T. bitextura*)	18	0
Frontage grass (various)	23	4 (17%)
Lowland curly spinifex (*T. bitextura*)	2	0
Marine couch (*Sporobolus virginicus*)	3	0
Mitchell grass alluvial plains (*Astrebla* spp., *Dicanthium* spp., *Chrysopogon fallax*, *Aristida* spp.)	74	0
Mitchell grass uplands (*Astrebla* spp., *Dicanthium* spp., *C. fallax*)	28	3 (11%)
Pindan (*T. bitextura*, *C. fallax*, *Eriachne* spp.)	34	9 (26%)
Plume sorghum (*Sorghum plumosum*)	4	0
Ribbon grass (*C. fallax*)	61	9 (15%)
Soft spinifex (*Triodia pungens*)	11	2 (18%)
Tippera tallgrass (*Themeda triandra*, *S. plumosum*)	3	1 (33%)
White grass (*Sehima nervosum*) – Bundle bundle (*D. fecundum*)	4	0
Total	306	34 (11%)

Table 2. An example of a Kimberley grassland site on which a negative transition was judged to have occurred

The frequency is provided for each grass species at each sampling date from 1995 to 2007

	Date 1	Date 2	Date 3	Date 4	Date 5	Change between date 1 and date 5
Sorghum plumosum	67	39	49	6	9	–58
Chrysopogon fallax	44	17	9	23	16	–28
Themeda triandra	7	2	6	2	1	–6
Aristida inaequiglumis	2	3	2	13	15	13
Sehima nervosum	37	28	77	36	72	35
Heteropogon contortus	14	61	58	90	87	73

situations, experience suggests that, if grazing management is fundamentally modified, the changes in species frequency will start to reverse, although the time frame to return to the original state may be decadal. However, in other cases, the increasing species, for example *H. contortus* in Ribbon grass vegetation type, is particularly persistent, and will continue to dominate even if the grazing pressure that drove the initial transition is removed entirely. Transitions were not restricted to a single direction. For example, in the Mitchell grass uplands type, the desirable perennial grass *C. fallax* (Ribbon grass) increased on one site but decreased on another (Table 3). Positive transitions were also seen on several other vegetation types such as Tippera tallgrass, Ribbon grass and Frontage grass. Positive transitions are almost certainly manifestations of state change from a degraded state. These degraded states are often the result of the early, exploitative years of pastoralism and the positive transition represents recovery from the degraded state.

As an example, in the Ribbon grass vegetation type, the most desirable state for pastoralism is dominated by the decreaser species *C. fallax* and other associated decreaser species, although increaser perennial and annual species are often recorded (see Watson *et al*. 2007*b*; for explanation of decreaser and increaser species). There were nine transitions recorded in the 61 sites assessed; of these, eight transitions could be characterised as being positive from a pastoral perspective [i.e. increases in decreaser perennial grasses, declines in increaser species (including annuals) or both]. The other site on which a transition occurred was characterised by a change from dominance by one perennial of limited preference by livestock (*Eriachne obtusa*) to another perennial also of limited preference (*Sehima nervosum*) but of a significantly different structure (small tussocks of 30–40 cm in height to larger tussocks of 80–100 cm in height) with little or no change in the limited abundance of the decreasers such as *C. fallax*.

Positive transitions included examples where decreaser perennials, such as *C. fallax*, increased substantially in frequency concurrent with a decline in increaser species, such as both annual and perennial *Aristida* spp., including the disappearance of one previously dominant increaser species. Alternatively, a limited increase in the frequency of decreaser perennial species was matched by the complete disappearance of previously dominant increaser perennials, biennials and annuals such as annual and perennial *Aristida* spp. and the biennial *Enneapogon polyphyllus*. Alternatively, transitions included a decline in *Aristida* species

Table 3. Examples of vegetation change within those vegetation types where at least three sites were judged to have made a transition or the changes were suggestive of a transition (see Tables 1 and 4)
A judgement of whether the transition was positive or negative, from a pastoral perspective, is provided in parentheses

Vegetation type (and dominant species)	Observed change
Bluegrass alluvial plains (*Dicanthium fecundum*)	Decrease in *Chrysopogon fallax* (Negative)
	Decrease in *D. fecundum* with increase in *Heteropogon contortus* and *Sorghum plumosum* (Negative)
	Decrease in *C. fallax* with some increase in *S. plumosum* (Negative)
Frontage grass (various)	Decrease in *Whiteochloa airoides* and *Eragrostis falcata* with increase in *C. fallax* (Positive)
	Increase in *C. fallax* along with increase in *Triodia pungens* or *D. fecundum* or *Eriachne obtusa* or some combination of these (Positive)
Mitchell grass uplands (*Astrebla* spp., *Dicanthium* spp., *C. fallax*)	Decrease in *Enneapogon polyphyllus* and *Aristida hygrometrica* with increase in *H. contortus* (Positive)
	Decrease in *Sorghum timorense* with increase in *C. fallax* and *Panicum decompositum* (Positive)
	Decrease in *C. fallax* with increase in *S. plumosum* (Negative)
Pindan (*Triodia bitextura*, *C. fallax*, *Eriachne* spp.)	Decrease in *Sorghum stipoideum* and to a lesser extent *C. fallax* (Negative)
	Decrease in *S. plumosum* and to a lesser extent *C. fallax* (Negative)
	Decrease in *T. bitextura* (Negative)
	Increase in some combination of *Sehima nervosum*, *S. plumosum* or *C. fallax* (Positive)
	Increase in *S. plumosum* with decrease in *T. pungens* (Negative)
Ribbon grass (*C. fallax*)	Increase in *C. fallax*, *H. contortus* and *Sorghum* spp. with decrease in *A. hygrometrica* (Positive)
	Decrease in *Aristida holathera* and *A. hygrometrica* with increase in *H. contortus* and to a lesser extent *C. fallax* (Positive)
	Decrease in *E. polyphyllus* with increase in *Cenchrus setigerus* and to a lesser extent *Triodia intermedia* (Positive)
	Decrease in *A. hygrometrica* and *E. polyphyllus* with increase in *S. nervosum* and *H. contortus* (Positive)
	Decrease in *E. polyphyllus* with increase in *C. fallax* and to a lesser extent *H. contortus* and *Aristida inaequiglumis* (Positive)
	Decrease in *Aristida* sp. with increase in *H. contortus* (Positive)
	Decrease in *Eriachne obtusa* with increase in *S. nervosum* (Neutral)
	Increase in *Eulalia aurea*, *S. nervosum* and *C. fallax* (Positive)
	Decrease in *Enneapogon* sp. and *A. inaequiglumis* with increase in *H. contortus* (Positive)
Hardpan mulga shrub (*Acacia aneura*, *Eremophila forrestii*)	Sites suggestive of a transition – on 6 of 7 sites an increase in *Acacia aneura* (increase in *Acacia victoriae* on the 7th site) with or without increases in some combination of *Acacia ramulosa*, *E. forrestii* and *Eremophila gilessii* (Negative)
Mixed halophytic (*Atriplex vesicaria*, *Frankenia* spp.)	Sites suggestive of a transition – increase in *Frankenia* spp. with decrease in *Maireana georgeii*, *Maireana glomerifolia* and *Maireana pyramidata* (Negative)
	Increase in *M. pyramidata* (Positive)
	Increase in *Atriplex bunburyana*, *Eremophila maculata* and *Frankenia* spp. (Positive)
Pearl bluebush (*A. vesicaria*, *Acacia papyrocarpa*, *Maireana sedifolia*)	Sites suggestive of a transition – increase in *A. papyrocarpa* (Positive)
Silver saltbush (*Atriplex bunburyana*)	Increase in *A. victoriae* with decrease in *A. bunburyana* or *Rhagodia eremea* (Negative)
Stony mixed chenopod (*Eremophila cuneifolia*, *Ptilotus polakii*, *Senna artemesioides*)	Increase in *Acacia tetragonophylla* and *Acacia xiphophylla* (Negative)
	Increase in *A. victoriae* (Negative)
	Increase in *A. victoriae* and decrease in *M. pyramidata* (Neutral)
	Sites suggestive of a transition – increase in some combination of *A. xiphophylla*, *E. cuneifolia*, *Hakea preissei* and *Senna artemisioides* subsp. × *sturtii* (Negative)

(increasers), both annual and perennial, but their replacement with intermediate perennial species such as *H. contortus* and *S. nervosum* and virtually no change in the recorded frequency of *C. fallax.* Stockwell *et al*. (1994) described similar changes in the *C. fallax* communities of the Northern Territory, to the east of the Kimberley.

Many sites showed considerable vegetation dynamics yet no transitions were determined to have occurred. Sites within the Mitchell grass alluvial plains vegetation type commonly fell into this category (an example is shown in Fig. 1). Despite substantial changes in species frequency of both increasers and decreasers, no transition to a different state was determined, as there was no defined, consistent trend in species composition.

Unlike the situation recorded in north-eastern Australia and the Northern Territory for similar vegetation types (McIvor and Scanlan 1994; Stockwell *et al.* 1994), threshold change incorporating significant increase in woody species was not found in any vegetation type in the Kimberley grasslands. On the WARMS sites, assessments of crown cover of woody species taller than 1 m were made (Watson *et al*. 2007*a*). Change in woody cover was extremely variable and transient, but no sites appeared to have crossed a 'woodiness threshold' over the period examined.

Of the 919 shrubland sites assessed in each of three assessment periods, transitions were observed on nine sites, or 1% (Table 4). On a further 24 sites (3%) change was observed 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 persistent.

Of the nine sites judged to have changed, the most common type of transition was associated with large increases in tall shrubs or trees, particularly *Acacia victoriae* (seven sites, see Fig. 2 for an example) but also *A. tetragonophylla* (one site) and *A. xiphophylla* (one site).

In the example shown in Fig. 2, *A. victoriae* numbers increased substantially at both the first and second re-assessments, while other *Acacia* species remained relatively constant. On this site, the desirable chenopod *Rhagodia eremea* showed a concomitant decline in numbers. Together, these changes suggest that the site had crossed a threshold to a more woody state.

On the sites suggestive of a transition, increases were observed for *Acacia aneura*, *Acacia papyrocarpa*, *A. ramulosa*, *A. victoriae*, and *A. xiphophylla* (Table 3), 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 a total of five sites on the Bladder saltbush and Pearl bluebush vegetation types. It is arguable, however, whether a chenopod community with a low density of *A. papyrocarpa* is in a different state to one with a higher density. 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 been a cause for concern for some time (e.g. Lange and Purdie 1976; syn. *Acacia sowdenii*), it was considered reasonable to include these five sites in the 24 suggestive of a transition.

Discussion

It is considered by the authors that this a preliminary exercise and it is acknowledged that the approach used to judge change of state is unsophisticated. It is clear, however, that thresholds continue to be crossed, albeit to a limited extent in shrubland sites, in the grazed rangelands of Western Australia. Both positive and negative transitions, from a pastoral perspective, were observed.

Transitions were more common in the northern grasslands than in the southern shrublands, perhaps because grassland species, predominantly grasses, are more dynamic than shrubs

Table 4. Number and vegetation type of Western Australian Rangeland Monitoring System shrubland sites assessed, number (and percent) of sites judged to have shown transitional change and number (and percent) of sites where transitional change was suggested

Vegetation type (and dominant species)	Number of sites assessed	Sites on which a transition was observed	Sites where transitional change was suggested
Acacia mixed shrublands (*Eremophila forrestii*, *Senna artemesioides*)	10	0	1 (10%)
Bladder saltbush (*Atriplex bunburyana*, *Atriplex vesicaria*)	72	0	1 (1%)
Currant bush mixed (*Ptilotus polakii*, *Scaevola spinescens*)	14	0	0
Gascoyne bluebush (*Maireana polypterygia*)	34	0	1 (3%)
Hardpan mulga shrub (*Acacia aneura*, *E. forrestii*)	212	0	7 (3%)
Mixed halophytic (*A. vesicaria*, *Frankenia* species)	128	0	3 (2%)
Other (*Acacia aneura*, *E. forrestii*, *Cratystylis subspinescens*, *Ptilotus polakii*)	25	0	0
Pearl bluebush (*A. vesicaria*, *Acacia papyrocarpa*, *Maireana sedifolia*)	97	0	4 (4%)
Riverine mixed (*Atriplex amnicola*, *S. artemesioides*)	10	0	0
Sago bush (*Maireana georgei*, *Maireana pyramidata*)	64	1 (2%)	1 (2%)
Sandplain – Acacia/mallee/pine shrub (*E. forrestii*, *Acacia ramulosa*)	15	0	1 (7%)
Sandy granite Acacia shrub (*A. aneura*, *Ptilotus schwarzii*)	21	0	0
Silver saltbush (*Atriplex bunburyana*)	25	3 (12%)	0
Stony – Acacia/Senna/Eremophila/Ptilotus (*E. forrestii*, *P. schwarzii*, *S. artemesioides*)	69	1 (1%)	1 (1%)
Stony mixed chenopod (*Eremophila cuneifolia*, *Ptilotus polakii*, *S. artemesioides*)	47	3 (6%)	3 (6%)
Tussock grass – miscellaneous (*S. artemesioides*)	5	1 (20%)	1 (20%)
Wandarrie grass (*A. aneura*, *E. forrestii*)	71	0	0
Total	919	9 (1%)	24 (3%)

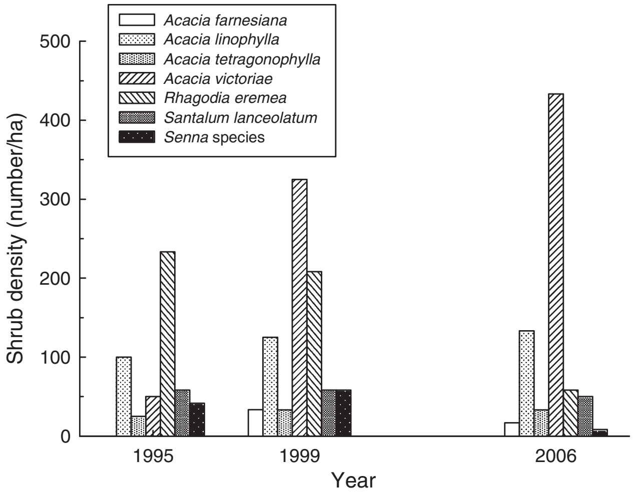

Fig. 2. Example of a Western Australian Rangeland Monitoring System shrubland site judged to have crossed a threshold, due to the large increase in *Acacia victoriae*, a tall shrub, and the decline of *Rhagodia eremea*, a preferred chenopod shrub. Note that an additional three species, *Acacia citrinoviridus*, *Acacia wanyu* and *Grevillea striata*, were also present on the site but have not been shown in order to improve presentation. They had maximum densities of 8.3 plants/ha (i.e. one individual on the site).

and trees, and species composition is able to change more rapidly. This is particularly the case given that the most of the Kimberley grassland sites are in areas with mean annual rainfall of 400–900 mm, while most of the shrubland sites are in areas receiving 200–250 mm mean rainfall and the perennial species found on them have slower turnover rates. Additionally, transitions were easier to identify over the four or five assessments for the grassland sites compared with the three assessments for the shrubland sites, i.e. the authors could be more certain that a persistent change had occurred.

The role of individual species in defining the direction of transition (positive or negative from a pastoral perspective) varies depending on both the vegetation type and the specific changes. A typical example is *H. contortus* which, when replacing non-preferred annual and perennial *Aristida* species, creates a positive transition. The significant increase in *H. contortus* across the Kimberley in the past 15 years (Fletcher 2011), however, has also been observed in areas previously dominated by *C. fallax*, with the increase in frequency of *H. contortus* at the expense of *C. fallax* reducing the pastoral value of the vegetation and suggesting a negative transition.

Most of the shrubland transitions were characterised by large increases in the density of *A. victoriae*. In some parts of Australia, *A. victoriae* is a short-lived low shrub and might be considered too transient to genuinely represent a state change. For example, a demographic study of 752 individual plants of *A. victoriae* in western New South Wales found that only 27% survived between 1981 and 1992 (Grice *et al*. 1994). Unpublished data (I. Watson) from long-term exclosures and grazing experiments, as well as observations from resource inventories (e.g. Payne *et al*. 1982) and monitoring sites in Western Australia, however, suggest that shrublands dominated by *A. victoriae* represent a persistent degraded state with individuals of the species surviving for multiple decades and high recruitment leading to persistent populations following initial encroachment.

It is feasible to suggest that some of the vegetation types now described for Western Australia's pastoral rangelands (see, for example, Stewart *et al*. 1970) are, in fact, states of other vegetation types at the landscape scale, and that these vegetation types are the consequence of pressures and drivers still evident today. As an example, the Arid short grass pasture type in the Ord Victoria grasslands of north-west Australia (dominated by the biennial *E. polyphyllus* and annual species), and described in Stewart *et al*. (1970), appears to be a state of the Ribbon grass type and has arisen as a consequence of excessive grazing pressure. This is demonstrated by data suggesting that complete removal of domestic and feral grazing pressure from *Enneapogon*-dominated grassland typically results over long periods of time in a significant increase in *C. fallax* and other species associated with Ribbon grass vegetation type, which replace the previously dominant annual/biennial species. Conversely, reduction but not complete removal of grazing pressure by domestic and feral species often leads to eventual dominance by *H. contortus* (A. Craig, unpubl. data).

What does the contemporary occurrence of changes of state mean for management and for regulation in Western Australia's rangelands? First, where a persistent change, at least within what could be termed a management time frame, 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 management context. Even substantial changes in species composition do not necessarily signify a decline in ecosystem function (Hibbard *et al*. 2003) or production potential (Norris *et al*. 2001). However, where the change is negative from a pastoral perspective, managers need to accept the new state and its altered productive potential as reality for the foreseeable future, and they will need to adjust their management to reflect the new vegetation community. Second, land administrators must accept that the capacity to enact a realistic and feasible management regime that will return the community to its previous state does not necessarily exist, and that requiring a change in vegetation that is ecologically unlikely under any management regime is pointless. Both condition assessment and prescribed management must be predicated on the fact that, while not a desired outcome, a threshold has been crossed, the ecology of the site has been altered and that reversal of the change may be difficult, independent of the management imposed. Management implications are also dependent on the transition mechanism. Where significant soil loss has occurred, management actions may have little effect over many decades and managers may need to focus recovery efforts elsewhere. In situations where excessive grazing, or some interaction of fire and grazing, has led to a negative transition, managers should impose specific management responses, which will eventually lead to the opportunity for positive change.

Despite the acceptance of the state and transition concept by rangeland scientists, there is little evidence that it has been incorporated into practical rangeland management. To date, land managers have generally had little contact with state and transition concepts, and their implications are rarely considered by land administrators in prescribed management actions. The percentage of grassland sites crossing a threshold was 11%. This suggests that transitions remain a contemporary phenomenon, one that is being experienced in realistic management time frames, and is not only a concept to describe changes that occurred decades in the past. It is suggested that greater interaction between land managers, scientists and land administrators is required to incorporate these concepts into decision-making at both the management and regulatory levels.

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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. doi:10.1111/j.1526-100X.2006.00140.x

Bestelmeyer, B. T., Goolsby, D. P., and Archer, S. R. (2011). Spatial perspectives in state-and-transition models: a missing link to land management? *Journal of Applied Ecology* **48**, 746–757. doi:10.1111/j.1365-2664.2011.01982.x

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. doi:10.2111/05-115R.1

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. doi:10.2111/07-051.1

Duckett, N. J. (1997). 'A Description of the Vegetation Communities of the Kimberley: an Analysis of Grassland Monitoring Sites.' Task Report for the Natural Heritage Trust-funded Project Development of Information Products for Reporting Rangeland Changes. (Agriculture Western Australia: Perth.)

Duckett, N. J. (2001). 'A Stratification of the Southern Shrubland WARMS Monitoring Sites.' A report for NLP/NHT Project Development of information products for reporting rangeland changes. (Agriculture Western Australia: Perth.)

Fletcher, M. (2011). Black speargrass in the Kimberley. *In*: 'Proceedings of the Northern Beef Research Update Conference'. August 2011. p. 156. (Northern Beef Research Council: Darwin.)

Friedel, M. H. (1991). Range condition assessment and the concept of thresholds: a viewpoint. *Journal of Range Management* **44**, 422–426. doi:10.2307/4002737

Grice, A. C., Westoby, M., and Torpy, C. (1994). Dynamics and population structure of *Acacia victoriae* Benth. *Australian Journal of Ecology* **19**, 10–16. doi:10.1111/j.1442-9993.1994.tb01537.x

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. doi:10.1890/1051-0761(2003)13[911:GTWTIC]2.0.CO;2

Jones, P., and Burrows, W. H. (1994). State and transition models for rangelands. 13. A state and transition model for the mulga zone of south-west Queensland. *Tropical Grasslands* **28**, 279–283.

Lange, R. T., and Purdie, R. (1976). Western myall (*Acacia sowdenii*), its survival prospects and management. *The Australian Rangeland Journal* **1**, 64–69. doi:10.1071/RJ9760064

McIvor, J. G., and Scanlan, J. C. (1994). A state and transition model for the northern speargrass zone. *Tropical Grasslands* **28**, 256–259.

Noble, J. C. (1997). 'The Delicate and Noxious Scrub: CSIRO Studies on Native Tree and Shrub Proliferation in the Semi-arid Woodlands of Eastern Australia.' (CSIRO: Canberra.)

Norris, M. D., Blair, J. M., Johnson, L. C., and McKane, R. B. (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., and Schoknecht, N. (2011). 'Land Systems of the Kimberley Region, Western Australia.' Technical Bulletin No. 98. (Department of Agriculture and Food Western Australia: Perth.)

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: Perth.)

Payne, A. L., Mitchell, A. A., and Holman, W. F. (1982). 'An Inventory and Condition Survey of Rangelands in the Ashburton River Catchment, Western Australia.' Technical Bulletin No. 62. (Department of Agriculture of Western Australia: Perth.)

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. doi:10.1007/s10980-006-0015-x

Scanlan, J. C. (1994). State and transition models for rangelands. 5. The use of state and transition models for predicting vegetation change in rangelands. *Tropical Grasslands* **28**, 229–240.

Stafford Smith, D. M., McKeon, G. M., Watson, I. W., Henry, B. K., Stone, G. S., Hall, W. B., and Howden, S. M. (2007). Learning from episodes of degradation and recovery in variable Australian rangelands. *Proceedings of the National Academy of Sciences of the United States of America* **104**, 20690–20695. doi:10.1073/pnas.0704837104

Stewart, G. A., Perry, R. A., Paterson, S. J., Traves, D. M., Slatyer, R. O., Dunn, P. R., Jones, P. J., and Sleeman, J. R. (1970). 'Lands of the Ord Victoria Area, Western Australia and Northern Territory.' CSIRO Land Research Series No. 28. (CSIRO: Canberra.)

Stockwell, T. G. H., Andison, R. T., Ash, A. J., Bellamy, J. A., and Dyer, R. M. (1994). Development of state and transition models for pastoral management of the golden beard grass and limestone grass pasture lands of N.W. Australia. *Tropical Grasslands* **28**, 260–265.

Stringham, T. K., Krueger, W. C., and Shaver, P. L. (2003). State and transition modelling: an ecological process approach. *Journal of Range Management* **56**, 106–113. doi:10.2307/4003893

Watson, I. W., Novelly, P. E., and Thomas, P. W. E. (2007*a*). Monitoring changes in pastoral rangelands – the Western Australian Rangeland Monitoring System (WARMS). *The Rangeland Journal* **29**, 191–205. doi:10.1071/RJ07008

Watson, I. W., Thomas, P. W. E., and Fletcher, W. J. (2007*b*). The first assessment, using a rangeland monitoring system, of change in shrub and tree populations across the arid shrublands of Western Australia. *The Rangeland Journal* **29**, 25–37. doi:10.1071/RJ07018

Westoby, M., Walker, B. H., and Noy-Meir, I. (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266–274. doi:10.2307/3899492

Whalley, R. D. B. (1994). Successional theory and vegetation change. *Tropical Grasslands* **28**, 195–205.

Whittaker, R. H. (1953). A consideration of the climax theory: the climax as a population and pattern. *Ecological Monographs* **23**, 41–78. doi:10.2307/1943519

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. (Western Australian Department of Agriculture: Perth.)