State and transition model for the *Eucalyptus porosa* (Mallee Box) low rainfall grassy woodland community of the eastern flanks of the Mount Lofty Ranges, South Australia

A report for Dan Rogers DENR by Ann Prescott 2011

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Mallee Box low rainfall grassy woodland community

In this model, we are including only that Mallee Box *Eucalyptus porosa* low rainfall grassy woodland which occurs in a relatively narrow but elongated north-south strip on the eastern slopes of the Mount Lofty Ranges (MLR) and at the eastern base of the ranges before the topography and soil changes to support mallee communities. The largest relatively intact areas are near Monarto to Murray Bridge and northwards towards Rockleigh.

Specht (1972) locates the *Eucalyptus porosa* low rainfall grassy woodland (as *Eucalyptus odorata* / *Eucalyptus porosa*) generally on the uphill side of *Allocasuarina verticillata* woodlands in its southern range, reversed in its northern range and intermixed in other areas. No *Lomandra effusa* grassland stands are mapped at this scale. This Specht records as “two land systems intergrade over a greater distance and transitional communities (ecotones) and .....extensive ecotones are found on the eastern side of the Mount Lofty Ranges.....”

Specht (1972) locates the *Eucalyptus porosa* low rainfall grassy woodland (as *Eucalyptus odorata* / *Eucalyptus porosa* / *Allocasuarina verticillata*) on the Palmer Scarp on coherent sandy soils, shallow grey-brown sandy soils Uc 6.11 (Northcote, 1968) and skeletal soils (Stephens, 1962) and on the northern Palmer Scarp on hard-setting, loamy soils with red, clayey subsoils, unbleached A2 horizon: alkaline reaction trend through profile Dr 2.23 (Northcote, 1968) and red-brown earths (Stephens, 1962). Irongrass grasslands are also listed under this second soil type.

Soils

According to the Atlas of South Australia, the area has the following 2 soil types:

Hard red duplex soils are probably the most important agricultural soils in the State. Their extent approximately defined the limits of the wheat belt in the nineteenth century. The subsurface soil consists of hard-setting loamy soil ranging from grey to brown to reddish brown. The boundary to the under-lying red-brown friable clay of the subsoil is usually abrupt. Previously known as red-brown earths, the hard red duplex soils are suitable for a wide range of cereal and horticultural crops. Gardens in parts of Adelaide owe much of their productivity and splendour to these soils. Surface soils are typically acid, but may be neutral to slightly alkaline. They are moderately permeable and have responded well to fertiliser applications. Gypsum has been found useful in ameliorating the hard-setting surface soils, and erosion controls, such as contour banks, are often desirable in order to slow rainfall runoff on sloping land.

Calcareous earths have gradational texture profiles that are calcareous throughout. They are widespread in the pastoral districts of South Australia and the drier margins of the agricultural districts. They have indistinct horizons and are typified by the brownish sandy and loamy soils of the 'mallee' lands. Calcium carbonate (lime) may range up to 10% in surface soils and 60% in subsoils. Some lime is hardened to calcrete (sheet limestone) or may be stony. Natural fertility is low to moderate, but the soils are easy to cultivate and their productivity for cereals in the agricultural regions has been greatly enhanced through the application of fertilisers and the use of medic pasture leys. Surface soils are neutral to alkaline, and subsoils are strongly alkaline. Where irrigated along the River Murray, these soils grow citrus, stonefruit and grapes; the deeper sandier soils are preferred for citrus.

http://www.atlas.sa.gov.au/images/2Env_Res4Soils.jpg

Location

The community of low open woodlands with dominant trees up to 10m high was probably originally widespread. According to Boomsma (1980) Mallee Box woodlands occur “Along the eastern margin of the MLR, rocky limestone ridges receiving about 300mm average annual rainfall.... Mallee Box may be the exclusive dominant but low open woodlands in association with other small tree species including *Callitris gracilis* and *Allocasuarina verticillata* are not uncommon.” (Boomsma, 1980) [Plant names updated.]

“On shallow, calcareous soils over sheet limestone in regions an average rainfall of about 300mm, Mallee Box can occupy the site exclusively to forma low open woodland.” (Boomsma, 1980)

“In a general way, discontinuous patches of mallee box occur as low open woodland on appropriate sites throughout the whole of the open scrub formations south of about 31^0S…”. (Boomsma, 1980) Latitude 31^0S runs through about Flinders Ranges National Park.

Good quality Mallee Box grassy woodlands characteristically have a strong association with *Lomandra effusa* and exhibit a tussock appearance with perennial *Lomandra effusa* tussocks up to about 50 cm tall at about 1m spacing. Hard Mat Rush *Lomandra multiflora ssp dura* is also often present. In wetter locations *Lomandra densiflora* may be present. However, tussocks can be absent in some areas. Specht (1972) observed that in iron grass communities “the density of the *Lomandra* spp. is lower in the valleys and the community here assumes more the characteristic of a grassland”.

Appearance and Species

The community tree layer is dominated by Mallee Box *Eucalyptus porosa*, although there may be the occasional emergent tree such as Drooping Sheoak *Allocasuarina verticillata*, Peppermint Gum *Eucalyptus odorata*, Native Pine *Callitris gracilis* and Blue Gum *Eucalyptus leucoxylon*.

Some existing *Lomandra effusa* natural temperate grasslands may be derived grasslands from Mallee Box grassy woodland or Drooping Sheoak grassy woodland. Known locations of *Eucalyptus porosa* woodlands indicate that *Eucalyptus porosa* and *Lomandra effusa* are strongly interconnected in these environments.

It is important to note that shrubs are more limited in both diversity and distribution with groves or patches of shrubs in an irregular pattern - compared to Stringybark communities. This must be taken into consideration in all revegetation projects.

Typical large shrubs might include:

Acacia pycnantha, Golden Wattle

Acacia retinodes, Wirilda

Exocarpus cupressiformis, Native Cherry

Melaleuca lanceolata, Dryland Teatree

Pittosporum augustifolium, Native Apricot

Medium shrubs might include:

Acacia argyrophylla, Silver Mulga-bush

Acacia calamifolia/euthycarpa, Wallowa

Acacia menzelii, Menzel’s Wattle

Acacia paradoxa, Kangaroo Thorn

Acacia rhigiophylla, Dagger-leaf Wattle

Bursaria spinosa ssp. lasiophylla, Downy Bursaria (about similar amounts as *Bursaria spinosa ssp. spinosa*)

Bursaria spinosa ssp. spinosa, Christmas Bush, Bursaria

Cassinia complanata (laevis), Sticky Cassinia, Curry Bush

Cassinia laevis, Curry Bush

Dodonaea viscosa ssp spathulata, Sticky Hop Bush

Dodonaea viscosa ssp. cuneata, Wedge-leaf Hop-bush

Pomaderris paniculosa ssp. paniculosa, Mallee Pomaderris

Rhagodia candolleana, Sea-Berry Saltbush

Rhagodia crassifolia, Fleshy Saltbush

Senna artemisioides ssp. coriacea, Broad-leaf Desert Senna

Senna artemisioides ssp. petiolaris (NC)', Flat-stalk Senna

Senna artemisioides ssp. var. filifolia, Fine-Leaf Desert Senna

Low growing shrubs might include:

Astroloma humifusum, Cranberry Heath

Atriplex semibaccata, Berry Saltbush

Einadia nutans, Climbing Saltbush

Enchylaena tomentosa, Ruby Saltbush

Eutaxia microphylla, Common Eutaxia

Gonocarpus elatus, Hills Raspwort

Maireana brevifolia, Short-leaf Bluebush

Maireana enchylaenoides, Wingless Fissure-Plant

Pimelea stricta, Erect Riceflower

Rhagodia crassifolia, Fleshy Saltbush

Rhagodia spinescens , Spiny Saltbush

Salsola kali, Buckbush, Roly-Poly

Also in the tussock matrix are grasses with flowering stalks to 1 m in a wide range of genera and with several species in the dominant genera.

Common grasses include:

Aristida behriana, Brush Wire-Grass

Austrodanthonia caespitosa, Common Wallaby-Grass

Austrodanthonia eriantha, Hill Wallaby-Grass

Austrodanthonia setacea, Small-flower Wallaby-grass

Austrostipa blackii, Crested Spear-grass

Austrostipa drummondii, Cottony Spear-grass

Austrostipa elegantissima, Elegant Spear-Grass

Austrostipa eremophila, Rusty Spear-Grass

Austrostipa mollis group, Soft Spear-grass

Austrostipa nitida group (NC)', Spear-grass

Austrostipa nodosa, Tall Spear-grass

Austrostipa platychaeta, Flat-awn Spear-grass

Austrostipa scabra, Rough Spear-Grass

Elymus scaber var. scaber, Native Wheat-Grass

Enneapogon nigricans, Black-head Grass

Homopolis proluta (panicum prolutum), Rigid Panic

Panicum effusum var. effusum, Hairy Panic

Setaria constricta, Knotty-butt Paspalidium

Themeda triandra, Kangaroo Grass

The soil in the inter-tussock gaps is protected by a thin layer of mosses, lichens and other cryptogams. In the inter-tussock gaps are many different perennial geophytes (regenerative points at or below ground level) with active winter-spring growth and late spring flowering and seeding. The inter-tussock plants include lilies, daisies, orchids, and other perennial herbaceous plants. These retreat or die down to underground parts in summer. In general the growth, flowering and seeding in the community is later in the season than in the sclerophyllous communities in the MLR such as Stringbark and Long-leaved Box communities.

Typical herbaceous plants include the following:

Acaena echinata var. (NC)', Sheep's Burr

Arthropodium fimbriatum, Nodding Vanilla-Lily

Arthropodium strictum, Common Vanilla-lily

Bulbine bulbosa, Native Leek

Caesia calliantha, Blue Grass-lily

Calostemma purpureum, Pink Garland-lily

Chamaesyce drummondii, Caustic Weed

Cheilanthes austrotenuifolia, Annual Rock-Fern

Chrysocephalum apiculatum, Common Everlasting

Clematis microphylla var. microphylla, Old Man's Beard

Convolvulus sp., Bindweed

Cullen australasicum, Tall Scurf Pea

Dichondra repens, Kidney Weed

Drosera whitakerii, Scented Sundew

Geranium pontilloides, Geranium

Glycine rubiginosa, Twining Glycine

Goodenia pinnatifida, Cut-leaf Goodenia

Goodenia pusilliflora, Small-flower Goodenia

Goodenia robusta, Woolly Goodenia

Goodenia willisiana, Silver Goodenia

Helichrysum leucopsideum, Satin Everlasting

Leptorhynchos squamatus ssp. squamatus, Scaly Buttons

Linum marginale, Native Flax

Maireana enchylaenoides, Wingless Fissure-plant

Oxalis perennans, Native Oxalis

Oxalis radicosa, Downy Native Sorrel

Plantago gaudichaudii, Narrow-leaf Plantain

Plantago varia, Variable Plantain

Ptilotus spathulatus, Pussytails

Stackhousia monogyna, Creamy Candles

Thysanotus patersonii, Twining Fringe-lily

Vittadinia cuneata var., Fuzzy New Holland Daisy

Vittadinia gracillis, Woolly New Holland Daisy

Wahlenbergia gracilenta, Annual Bluebell

NOTE: Plant lists in this report are based largely on Seager (2011), Hyde (1995); Davies (1997); Robertson (1998); and DENR databases (2011).

Indicator species for these Mallee Box woodlands might include Downy Bursaria *Bursaria spinosa ssp. lasiophylla*, Downy Native Sorrel *Oxalis radicosa, Cassinia laevis*, *Cassinia arcuata*, and *Maireana rohrlachii*.

Effects of Fire

In the areas without Mallee Box trees, fire is considered to have been a normal part of the natural community pre-European. The regenerative point of most species is at ground level or below. It is believed that fires occurred at relatively frequent intervals (although fire frequency is not known definitively). In the (rare) more

fertile areas, the tussock grasses build up thatch[1] over a number of years, which can impede the annual growth of new leaves and culms up through the tussock. This thatch also reduces the inter-tussock spaces in which the perennial geophytes grow and flower. In contrast, fire reduces the size and competitiveness of the tussocks in the short term, and opens up the inter-tussock space allowing the inter-tussock herbs and forbs to exploit the space under less competition. Fire may also stimulate flowering of the grasses. However, *L*. *effusa* can be affected by several fires at too frequent intervals, particularly if grazing follows the fire(s).

Fire followed by grazing can lead to the elimination of *Allocasuarina verticillata* and result in derived grasslands. *Allocasuarina verticillata woodlands* are seriously under-represented in the remaining vegetation in this area, although some of those remaining pockets have a quite high diversity.

Some nutrient build-up and importation of pasture weeds has occurred in *Eucalyptus porosa* low rainfall grassy woodland which has been subjected to sheep grazing from very early days after the arrival of Europeans. It may have been aerial fertilized along with legumes in the 1950s when wool prices were high and artificial fertilisers were cheap, but this is no longer considered economically viable.

Weed invasion is also a threat to the woodland. Annual weed grasses grow well in the inter-tussock spaces in high rainfall years and reduce the number and vigour of the native inter-tussock geophytes and substantially reduce its value as habitat for fauna. In addition, the exotic perennial geophytes Wild Sage *Salvia verbenaca* and *Romulea rosea* effectively replace the native species as grazing pressure increases and life form diversity decreases.

Model considerations

An important aspect of all biological systems is that they are dynamic and differences will be observed between sites and through time due to a combination of environmental conditions and site history (including past and present management). Knowledge of the way that ecological systems change under different conditions and ultimately how these differences are manifested is fundamental for successful conservation management. In particular, understanding dynamics, and how the system is most likely to respond (change) as a result of various phenomena (including management actions) will help guide decision making.

This State and Transition Model is an attempt to capture the complex dynamics observed within the biological system. The model describes a series of alternative meta-stable states along with the types of actions and processes that cause transitions between these states.

The model uses terminology based on that of Stringham *et al*. (2003), as summarized below:

- State: a recognizable, stable, resistant and resilient abiotic/biotic complex. A state encompasses a certain amount of variation in space and time.
- Transition: a trajectory of change away from the current stable State that is triggered by natural events, management actions, or both.
- Boundary (asymmetric threshold): asymmetric boundaries in composition or function that occur in space and time and delineate States. At a Boundary, small changes in environmental conditions lead to large state changes. When a Boundary is crossed one or more of the primary ecological processes has been irreversibly changed and must be actively restored before return to a previous State is possible.

Each State in the model is accompanied by a description that includes: the general characteristics of the State; the types of historical management actions typical of sites now in the State and indicators of the State. Because of the nature of grassland systems, potential restoration actions that may improve the conservation value or bring about a transition to a better State (from a biodiversity management perspective) are not state specific. Hence a generic section on grassland restoration is provided, rather than considering restoration for each state.

[1] Thatch is grass stem and leaf material that is now dead but remaining *in situ*, either upright within tussock or fallen and lying +/- parallel to the ground in the case of annual grasses.

As far as practical, States within the model and the indicators used to describe them have been subjected to a process of field validation. That said, because these models are (by necessity) a simplification of the natural world, they may not be definitive in all cases. For this reason, where the model is being applied for decision making, the process should actively incorporate all relevant local site history and other idiosyncrasies. Nevertheless, the indicators can be used to help ascertain the likely State of a site or in combination with history and tenure data, a generalized impression of condition across a landscape.

Indicators should be considered as evidence for a site being in a given State, but not in an absolute sense. That is, the greater the number of indicators agreeing with a particular State, the higher the likelihood of a site being in that State, albeit natural complexity means there will potentially be some exceptions.

In many cases appropriate application of the indicators will allow for the State of a site to be identified, especially if it is possible to augment the information with local history. Where States cannot be determined definitively from the indicators, they will still be of practical use in narrowing down the range of possible alternatives to the two or three most likely. From there, the acquisition of additional history information or undertaking small scale manipulation of the site will enable a more confident determination.

State and Transition Model

State 0 – Pre-European intact grassy woodland

Characteristics

Close to State 0: Heterogeneity in the structure, composition, and diversity of the community. Open tussock structure understorey.

State 0 is the community in its Pre-European condition. This state would have had Mallee Box trees of all ages. Very mature tree are spreading and often have several thick trunks. Iron-grass tussocks, would not necessarily provide the visual dominance but almost always occur. The Iron-grass tussocks may have been absent in some small areas (eg valleys). A wide range of native tussock grasses would have been present; both in genera and in species, standing erect to ≥ 1m. Both Iron-grass tussocks and grass tussocks of all ages would have been present. Typical co-dominants would have included *Aristida behriana*, *Austrodanthonia caespitosa*, *Austrostipa blackii*, *Austrostipa eremophila*, *Austrostipa nitida*, and *Themeda triandra*.

There would have been a wide range of geophytes in the inter-tussock spaces. Above the ground layer of tussocks and herbaceous species, there would have been scattered shrubs or shrubs in groves.

This community would have had no weed species, little soil disturbance, good water filtration, and no erosion. The normal ecological processes of energy flow, nutrient cycling, mixed age classes, competition, cooperation, diversity, heterogeneity, interdependence, and adaptation would all be functioning.

The species list was realistically over 100 species with up to 8 grass genera and 20 grass species, and with 80 annuals and geophytes.

It is important to note that there would have been a reasonable degree of heterogeneity in the structure, composition and diversity of the community, and in particular the location and density of both the Mallee Box and shrubs as well as the Iron-grass tussocks across the landscape based on the underlying environment (soil type and topography, and between the wetter and drier limits of the range).

Management, impacts and disturbance

By definition this state would not have been impacted by Europeans. There would have been intermittent grazing by native animals and intermittent fires.

State indicators

This state no longer exists.

Transition indicators

State 0 transitions to State 1 or State 9 if cleared.

Boundary indicators

NIL

State 1 – Remnant intact grassy woodland

Characteristics

State 1: Mature trees, good understorey, old and young trees, forbs and perennial grasses

State 1 is very similar to State 0 but it is now within a fragmented altered landscape. Patches are separated by areas that have been modified, most commonly grazed and / or cleared, ploughed and cropped. The timing and frequency of processes such as fire and grazing by native animals has been altered. This has in turn led to changes to the composition of the community, in particular invasion of non-native species. A change in numbers and species of fauna will have occurred, particularly medium-sized marsupials. Some annual weeds such as *Avena barbata / fatua,* Bearded Oat, and Smooth Cat's-ear *Hypochaeris glabra* would be present in the inter-tussock spaces even in this State due to fragmentation and grassy woodland areas being utilised very early during the development of modern Australia.

Diversity is likely to consist of more than 80 species with up to 10 grass genera and 15 grass species. The most species rich sites would be those which comprise a diversity of landforms including broad low rocky ridges of shallow but heavy soil, as well as containing shallow drainage lines with better developed soil (Davies, 2010).

A range of herbaceous species such as native peas, lilies, and usually orchids would be present. There will be limited thatch biomass (less than 10%) in the native grass tussocks and visible gaps between tussocks, although the actual amount of bared ground will be minimal as a thin crust of cryptogams would cover most exposed ground surface.

Management, impacts and disturbance

Remnant areas are likely to be managed benignly as unmodified grassy woodland (along roadsides, railway corridors, cemetery surrounds, Crown land reserves, and council reserves), for conservation, or for seasonal or drought grazing reserves (i.e. only infrequent light grazing employed). Small isolated rocky islets or ridges of grassy woodland may occur in cropping paddocks; however, where these may be heavily grazed as part of the paddock when sheep were introduced to graze stubble would not be State 1.

These areas will have changed (reduced?) burning patterns and changed (reduced?) grazing patterns. For this system, the aptitude and direction of both of these changes are unknown with unknown consequences. That said, some loss of very sensitive plant species (e.g. orchids) and reduced density of other species as well as localised weed invasion by annuals is expected, as is reduced reproductive output.

Management experience in related systems has shown that intact grassy systems may be prone to build up excess thatch (derived from native perennials) in the absence of suitable disturbance (e.g. occasional wildfire, native macropod grazing). In such systems, changes to these processes at a landscape scale means that some management intervention is necessary to avoid a transition to a thatch dominated state. However, in less productive grassy woodlands, native grass thatch has not been found to build up in the absence of disturbance such that interstitial spaces are compromised (Prober & Thiele, 1995; Milchunas *et. al*., 1998, cited by Davies 2010). With respect to *L. effusa* remnants within the current study area, this native thatch phenomenon is likely to be restricted to wetter sites dominated by Kangaroo Grass *Themeda triandra*. Thatch impacts resulting from exotic biomass are, however, likely to be important in degraded States and are considered in these subsequent States.

State indicators

- Adjacent to land not vegetated with original native vegetation
- Minor annual grass and herbaceous weeds present (less than 5% biomass) over at least some of the area, including:

  Smooth Cat's-ear, *Hypochaeris glabra*

  Bearded Oat, *Avena barbata / fatua*
- Species list may have up to 60 species and includes species from a range of life forms (perennial and annual grasses, perennial and annual geophytes).
- Presence of orchids.
- Presence of small shrubs with fragile stems such as *Maireana rohrlachii.*
- Presence of grazing sensitive perennial grasses such as:

  Elymus scaber var scaber Native Wheat Grass
- Presence of summer growing perennial grasses such as:

  Aristida behriana, Brush Wire-grass

  Homopolis proluta (Panicum prolutum), Rigid Panic

  Panicum effusum var. effusum, Hairy Panic

  Setaria constricta, Knotty-butt Paspalidium

  Themeda triandra Kangaroo Grass

Transition indicators

State 1 transitions to State 2, State 4b, very rarely State 3 or State 5, and State 9 if cleared.

Boundary indicators

B1 Interrupted and altered natural ecological processes due to European presence and influence. Loss of continuum in time and space stops return to State 0.

State 2 – Grassy woodland impacted by light intermittent grazing

Characteristics

State 2: Mature trees good understorey but not enough forbs, not enough age classes of trees

This State 2 describes remnant native grassy woodland impacted by irregular and / or discontinuous grazing by stock at a low stocking rate, usually for economic gain.

The first major impact of regular grazing is the effect on individual plant vigour and the structural appearance of the community. It causes a structural change to the strata with reduction of overall height of the understorey strata as well as reduced flowering, seeding, reproduction and recruitment in most layers. Loss of community structure can have a flow on effect to native fauna, although remnant *L. effusa* tussocks and rocks will provide refuge for a range of reptiles (Schofield, pers. comm.).

A change to the composition of the community is the second major impact resulting from grazing. Grazing and reduced flowering will lead to the loss of some species with short viability seeds. Palatable species such as lilies, daisies and orchids are preferentially grazed and are the first species to disappear from grazing-impacted grassy woodland (Lunt, 1991 cited by Davies, 2000). Further research is required to produce a definitive list of grazing sensitive species (Davies, pers. comm.).

The third major effect of regular grazing is the importation of the seeds of annual grasses and herbaceous species and of a wider range of weed seeds through stock droppings and through putting out hay bales as feed in dry seasons. The annual grasses actively grow during the rainy months of winter and spring. When the annual grass growth is greater than can be consumed by stock, they flower, set seed, die and fall as inter-tussock thatch. There is now a greater loss of inter-tussock species, being replaced by introduced annual grasses.

The last major effect of regular stock grazing is at the soil level. The hard hooves of stock lead to some bearing of the ground, with soil crust damage, and increased erosion potential.

Common native grasses remaining in the system, depending on past grazing pressure, are likely to include some of the following:

Aristida behriana, Austrodanthonia caespitosa, Austrodanthonia setacea var setacea, Austrostipa blackii, Austrostipa drummondii, Austrostipa elegantissima, Austrostipa eremophila, Austrostipa nitida, Austrostipa nodosa, Austrostipa scabra, Elymus scaber var scaber, Lomandra densiflora, Lomandra effusa, Lomandra multiflora ssp *dura,* and *Themeda triandra.*

Common native herbaceous species are likely to include:

Convolvulus erubescens, Chamaesyce drummondii, Glycine rubiginosa, Goodenia pinnatifida, Goodenia pusilliflora, Maireana enchylaenoides, Oxalis perennans, Calostemma pupureum, Ptilotus spathulatus, Vittadinia cuneata, Vittadinia gracilis, and *Wahlenbergia luteola*

Shrubs and emergent trees are likely to include *Bursaria spinosa var lasiophylla, Acacia pycnantha*, and *Allocasuarina verticillata.*

Management, impacts and disturbance

Management is for profit by grazing the native grassy woodland community. This is a low cost grazing option as few inputs would be used. In this State, the grassy woodland would have been regularly spelled over summer and not subject to prolonged and / or heavy grazing. Some loss of winter-growing native species is expected as well as weed invasion particularly by species not favoured by stock.

As a significant number of woodland species are active summer growers, and there may be semi-regular summer rain in this community, this may be less threatening than in other kinds and locations of woodlands such as the western flanks of the MLR. However, this has not been substantiated.

State indicators

- Presence of grazing, or signs of recent grazing such as droppings*
- Loss of some flowering and seeding events
- Minor loss of biomass of native species
- Loss of some height structure with flow-on of some fauna habitat loss
- Most plants reduced in height and vigour*
- Disturbed cryptogam crust*
- Grasses growth, particularly flowering culms, parallel to ground rather upright*
- Species list may have between 20 and 30 species
- Some loss of grazing sensitive (more palatable) species, especially perennial forbs and winter-growing species.
- Additional grass and herbaceous weeds present
- Common weed grasses may include;

    Aira cupaniana, Small Hair-grass

    Avena barbata / fatua, Bearded Oat

    Briza maxima, Large Quaking-grass

    Bromus sp, Brome

    Ehrharta longiflora, Annual Veldt Grass

    Hordeum leporinum, Barley Grass

    Lagurus ovatus, Hare's Tail Grass

    Pentaschistis airoides, False Hair-grass\

    Rostraria cristata, Annual Cat's-tail

    Vulpia sp, Silver Grass

- Common herbaceous weeds may include:

    Hypochaeris glabra, Smooth Cat's Ear

    Hypochaeris radicata, Rough Cat's Ear

    Trifolium angustifolium, Narrow-leaf Clover

    Trifolium arvense var. arvense, Hare's-foot Clover

    Trifolium campestre, Hop Clover

    Moraea setifolia, Thread Iris

    Romulea minutiflora, Small-flower Onion-grass

    Romulea rosea, Guilford grass

- Absence of permanent water points (i.e. lack of water thereby precluding summer grazing)

NB: * These indicators will only be of use for recent grazing activity, longer term and or historic impacts will need to rely on species indicators.

Transition indicators

State 2 transitions to State 3, State 4a, State 4b, State 6, or sometimes State 3 and State 9 if cleared.

Boundary indicators

B2 Loss species and propagules of grazing sensitive species; in this area mainly grazing-sensitive winter growing species, a few grazing resistant weeds invade and side effects of grazing stops return to State 1.

State 3 – Grassy woodland dominated by excess grass thatch

Characteristics

State 3: Grazed, no nutrients. Missing some herbaceous species, missing shrubs, some annual weedy grasses

State 3 represents the community with excess exotic thatch biomass between the native grass tussocks. In these environmental settings this may not often occur except for valleys and roadsides. Eventually the build-up of annual weed grass thatch creates an environment in which native grass germination and native herb growth is compromised and reduced. There will be a reduced abundance and diversity of native inter-tussock species and a reduction in flowering events of native tussocks. The accumulation of thatch in the inter-tussock space may also affect fauna use of habitat, especially reptiles, by reducing movement ability and creating shade (Schofield, pers. comm.). Predators such as spiders and birds are also less likely to be able to detect and catch prey in this State. (Paton, pers. comm.)

This state is mainly derived from State 1 (benignly managed) OR from State 2 (light infrequent grazing) in environments where annual weeds have become established and biomass accumulation is not now regulated through grazing or fire. In this case, thatch build up has occurred both within the native grass tussocks and between the tussocks by annual weedy grasses to a point at which it has reduced the vigour and flowering of the native tussocks and the annual weed thatch has smothered and out-competed the native wildflowers.

Studies have shown higher concentrations of available nitrogen in topsoils where annual exotic species dominate. Prober *et al*. (2002) hypothesise that a positive feedback loop exists whereby annual exotic grasses such as *Avena* spp. are promoted by higher available nitrogen. When these short-lived plants die and decay this nitrogen is released back into the soil, creating suitable conditions for the next germination of annual exotic grass seeds following autumn rainfall. Conversely, long-lived perennial native grasses store nitrogen within their biomass (Prober, *et al.*, 2002) and do not generate the same seasonal peaks in nitrates. Successful restoration requires breaking this positive feedback cycle and taking actions to deplete soil nitrates (Prober, *et al.*, 2005).

Management, impacts and disturbance

This State is the result of either no grazing and / or fire or by very infrequent grazing of an area that has had previous grazing and has lost some native plant diversity. Annual grass and herbaceous weeds have invaded and become common. The State may also come about as part of a restoration strategy following a reduction in grazing in the absence of alternative biomass management actions; however in this instance native species diversity is likely to be less.

Common weed grasses may include Wild Oats *Avena fatua,* Large Quaking-grass *Briza maxima*, Barley Grass *Hordeum leporinum,* False Hair-grass *Pentaschistis airoides,* Hare's Tail Grass, *Lagurus ovatus,* Bromes *Bromus spp,* Annual Veldt Grass *Ehrharta longiflora, and* Small Hair-grass *Aira cupaniana.*

Common herbaceous weeds may include Smooth Cat's Ear *Hypochaeris glabra,* Onion-grass or Guildford Grass *Romulea spp*., Hare's-foot Clover *Trifolium arvense var. arvense*, Hop Clover *Trifolium campestre*, Rough Cat's Ear *Hypochaeris radicata*, Narrow-leaf Clover *Trifolium angustifolium*, Thread Iris, *Moraea setifolia*, Hairy Plantain *Plantago bellardii*, Cape Weed *Arctotheca calendula,* and Salvation Jane *Echium plantagineum*.

The State is characterised by reduced species richness per site, annual weed invasion, and exotic annual grass thatch favouring the germination of additional exotic annual grass.

State indicators

- Build-up of lying thatch, usually *Avena* spp. to a depth of over 5 centimetres, may vary seasonally
- Cryptogam crust reduced or lack of cryptogams
- Annual introduced native grasses and herbaceous species present
- Some loss of native species, especially geophytes

Transition indicators

State 3 transitions to State 10a, or rarely State 5 if neglected, and State 9 if cleared.

Boundary indicators

B3 Lost inter-tussock structure and excess annual grass biomass. Loss of species requiring open inter-tussock spaces. Addition of some weeds and some biomass accumulation stops return to State 2 or State 1.

State 4a – Grassy woodland seriously impacted by grazing

Characteristics

State 4a: comparison showing loss of herbaceous species cross fence and Sheoak deaths (left) and loss of herbaceous species (right)

This State describes remnant native grassy woodland impacted by regular and continual grazing by stock for economic gain. This is a common state in the eastern flanks of the MLR.

State 4 comes as the result of further degradation from State 2 where the impact of grazing has modified the community to a significant degree with loss of species, soil modifications, and (while grazing practices are active) serious modification of the tussock and inter-tussock appearance of the community.

It is likely that there has been over-grazing for a number of years without seasonal spelling. There will be loss of native inter-tussock species, and an increase in non palatable species, including annual grasses in winter and

an increase in broad-leaf ground layer weeds such as Potato Weed *Heliotropium europaeum*, Cape Weed *Arctotheca calendula*, and Salvation Jane *Echium plantagineum*. Summer rain will exacerbate this.

Native grass tillers grow parallel to ground rather than upright, and there will be thinning of shrub layers through trampling of aerial parts of plants. There may be a reduction in flowering culms as the grazing pressure does not allow the grasses to 'bulk-up' enough to produce flowers.

Commonly occurring native grasses in this State are likely to include some of the following: *Aristida behriana*, *Austrodanthonia caespitosa*, *Austrostipa eremophila*, *Austrostipa nitida*, *Enneapogon nigricans*, *L. effusa*, and *L. multiflora* ssp*. dura*, according to Robertson (1998).

Very commonly occurring native herbaceous species in this State are likely to include some of the following: *Goodenia pinnatifida*, *Glycine rubiginosa*, *Vittadinia cuneata*, *Vittadinia gracilis*, and *Wahlenbergia luteola* (Robertson 1998). In addition Robertson lists the grazing resistant native *Ptilotus spathulatus*, *Oxalis perennans*, *Convolvulus erubescens*, *Chamaesyce drummondii*, and *Maireana enchylaenoides*.

Commonly occurring weedy grasses in this State are likely to include some of the following: *Avena* spp*, Bromus diandrus / B. rigidus, Bromus rubens, Rostraria cristata,* and *Vulpia* spp. (Robertson 1998).

Commonly occurring weedy herbaceous plants or geophytes in this State are likely to include some of the following: Potato Weed *Heliotropium europaeum*, Thread Iris *Moraea setifolia*, *Romulea* spp., *Salvia verbenaca*, *Echium plantigeum*, *Erodium* spp., *Carthamus lanatus*, *Hypochaeris* spp., *Medicago* spp, *Trifolium* spp., *and Sonchus oleraceus*. The woody weed *Marrubium vulgare* is also likely to be present (Robertson 1998).

There will be soil compaction leading to poorer water retention and greater erosion, and increased bare soil particularly in summer when plant growth is insufficient to adequately carry the stocking rate.

The worst state may be bare ground plus the toxic Potato Weed *Heliotropium europaeum.*

Fauna species dependant on cover, such as reptiles, will no longer be present (Schofield, pers.comm.).

Management, impacts and disturbance

Management is for economic return. Grazing is continuous with no spelling and grazing pressure is regularly beyond carrying capacity so that non-palatable species increase, native species reduce in diversity, abundance and size, and soil is bared in summer with non-palatable ground hugging weeds present.

State indicators

- Change in structure of soil with compaction and erosion
- Bare ground in summer or covered with broadleaf non-palatable weeds such as *Erodium cicutarium*
- Common broad-leaf, perennial / geophyte weeds can include: *Heliotropium europaeum*, *Moraea setifolia*, *Romulea* spp., *Salvia verbenaca*, *Echium plantigeum*, *Arctotheca calendula*, *Erodium* spp., *Carthamus* spp.
- Non-*Lomandra* tussock species will be less than 5 cm high and exhibit a growth form parallel to the ground, grass inflorescence, if any, will also be short and parallel to the ground
- Native grass tussocks and amongst rocks of rocky ridges are the only refuge for forbs
- Recruitment confined to tussocks
- Species list may have up to 10 native species
- Adjacent to cropping land and proximity of watering points allows year-round grazing.

Transition indicators

State 4a transitions to State 7 if fertilised or State 5 if grazing stops and neglected or State 9 if cleared.

Boundary indicators

B4 Loss of grazing sensitive species, Significant loss of annual and herbaceous species and changed habitat and soil structure and nutrient changes stops return to State 2.

State 4b - Grassy woodland impacted by loss of tree layer

Characteristics

State 4b: cross fence comparisons showing loss of sheoaks from left side of fence

This State describes remnant native grassy woodland impacted by loss of the tree layer. This is particularly true for the *Allocasuarina verticillata* Sheoak woodlands, where the life of the trees is, say, 80-100 years rather than 200 years for the Eucalyptus woodlands. The effects for Sheoak woodlands are more obvious but the issue is also significant for Eucalyptus woodlands as the age of the Eucalyptus trees is also increasing towards senescence with inadequate regeneration.

It also includes woodland areas where the mature Eucalyptus trees have been cut down or thinned out for timber, fence posts, firewood or ringbarked to increase growth of the ground cover.

It also includes degraded states such as ploughed fields where remnant mature trees are lost through senescence.

State 4b can come from most states and the effects are similar regardless of the state from which it derives.

Management, impacts and disturbance

Management is often benign as the loss of trees is a gradual side-effect of grazing and is often considered to be of minor consequence when grazing or cropping for economic return, compared to the biomass at the ground layer. Occasionally it will be active, cutting trees for firewood or fence posts.

The woodland lacks the structural layer of trees. This has a flow on effect for particularly birds (and bats) with the loss of such factors of roosts, nesting sites above the ground, protection from raptor predation, hollows of a wide range of sizes for shelter and nesting, flushes of nectar or pollen during flowering, loss of insects for insectivores, perches for ground pouncing woodland birds.

A secondary flow-on effect is loss of logs on the ground for reptiles.

State indicators

- Loss of tree layer
- No significant age diversity within any existing tree layer
- Loss of structural / height diversity for birds, bats, and arboreal mammals
- Loss of logs of a range of sizes on the ground for reptiles.

- Increase in annual weed biomass as the control effects of the trees over water and nutrient availability, and shade diminishes.

Transition indicators

State 4b is an and state in terms of trees lost unless actively managed for trees or transitions to State 9 if cleared.

Boundary indicators

B8 Loss of tree layer, its resources, and its structural elements including fallen branches and loss of logs, regardless of the composition of the plant understorey. This renders it less suitable for sustaining birds and / or reptiles and stops return to previous States.

State 5 – Perennial weed dominated grassy woodland

Characteristics

State 5: Perennial weeds out-compete and change the structure of the community

State 5 comes from States 1, 2, 3 and 4 following the introduction of highly competitive perennial weeds including grasses and forbs and where there is no follow-up management of weeds. The overall biomass is taken up by increased weed burden and the increasing abundance and biomass of perennial species.

The system has a thatch dominated ground layer of *Avena* spp., *Hordeum* spp., *Lolium rigidum*, (>80% biomass) and herb invasion – *Moraea setifolia*, *Romulea rosea*, *Salvia verbenaca*, (>20% cover). Some weedy shrub invasion may occur including *Lycium ferocissimum*, *Gomphocarpus rotundifolia*, and *Marrubium vulgare*, (>20% cover).

Highly invasive Bridal Creeper *Asparagus asparagoides* will increase in abundance.

The perennial grass *Pentaschistis pallida* is likely to increase and spread across properties. There is some concern, but no scientific data, to suggest that *Pentaschistis pallida* is alleopathic, suppressing growth of native species in the near vicinity, increasing its advantage and spread (NGRG, pers.comm.).

An active watch for other perennial woody weeds should occur as these are now being established in orchards and plantings along the eastern flanks or have been seen growing wild along roadsides in several places and are difficult to eradicate once established. These include (alphabetically) and most serious marked with [##]:

Asteriscus spinosus, Golden Pallenis

Chondrilla juncea, Skeleton Weed[##]

Eragrostis curvula, African Love Grass[##]

Foeniculum vulgare, Fennel

Galenia pubescens, Galenia

Gazania linearis, Gazania[##]

Hypericum perforatum, St Johns Wort

Olea europaeus, Olive[##]

Pinus sp, Pine[##]

Rosa canina or Rosa rubiginosa, Dog Rose[##]

Management, impacts and disturbance

This State may occur following a change in land use (e.g. removal of grazing on disturbed land with weed species present), or alternatively may occur on less disturbed sites adjacent to suitable weed sources such as ploughed fields.

State indicators

- Perennial woody weeds may be present including Broad-leaf Cotton-bush *Gomphocarpus rotundifolia*, Horehound *Marrubium vulgare*, African Boxthorn, *Lycium ferocissimum*. Where Horehound *Marrubium vulgare* is dominant, native perennials may be already lost.
- Highly invasive non-woody perennial weeds present such as Soursob *Oxalis pes-caprae*, Bridal Creeper *Asparagus asparagoides* and exotic perennial grasses (e.g. *Pentaschistis pallida*) present
- Thatch in the ground layer from annual grasses increases
- Reduced recruitment (lack of juvenile plants)

Transition indicators

State 5 is an end state unless actively managed for weeds or State 9 if cleared.

Boundary indicators

B6 Lost openness of structure. Increased density of the low-, mid- and/ or overstorey reducing its value as woodland habitat stops return to State 3 and State 1.

State 6 – Grassy woodland impacted by nutrient enrichment

Characteristics

State 6 comes from State 2 [or State 3] following the introduction of nutrients through fertiliser use and legume seeding, and / or sheep urine and droppings and legume seeds through sheep droppings. Legume seeds such as Trifoliums come onto the property in sheep wool and guts from wetter districts where Trifoliums are sown for their nitrogen fixing properties. In the past, mainly in the 1950s, there may have occasionally been nitrogen and phosphorus fertiliser added on these flanks. Since then, this practice has become uneconomical. Any recent fertiliser additions are likely to be the result of drift and drainage from adjacent cropping lands or on lifestyle properties where sheep grazing is not strictly an economic proposition.

Nutrients promote the growth of annual grasses and weeds and this also leads to increased grazing pressure through higher grazing rates and often continual grazing. Some native species also do not respond well to the increased nutrients.

The winter growth and increased biomass of annual weed grasses may lead to an accumulation of thatch present over summer. As discussed for State 3, nutrient cycles will promote exotic grass growth.

The increased annual grass growth and thatch means that there is less bare ground and fewer cryptogams. The annual grasses in the inter-tussock space may reduce the suitability of this state for a range of native ground dwelling fauna.

State 6: Understorey annual grass biomass favoured by nutrients have become dominant

Management, impacts and disturbance

Management is generally for economic gain using grazing stock. Nutrient levels and annual legumes drive the system towards a winter biomass system rather than the natural winter and summer biomass cycle.

Nutrients lead to growth of exotic grasses and forbs which compete with and reduce the growth and recruitment of native grasses and herbaceous species in the inter-tussock space.

Jessup (1948) in Specht (1972) considered that the system managed in this way would often have about 7 common species of native perennial grass in 5 genera, plus the native herbaceous species *Dianella* plus 2 *Lomandra* species.

Weeds would commonly include 6 species of common annual weed grasses in 6 genera and a general greater abundance weedy herbs and grasses.

State indicators

- Similar appearance to the grazed State 2 and State 3 except for more annual grass biomass
- Flush of annual grasses in winter
- Reduced recruitment of native species (lack of juvenile plants)
- Limited native species diversity (<15 species).
- Weeds

  Arctotheca calendula, Cape Weed

  Carthamus lanatus, Saffron Thistle

  Cirsium vulgare, Spear Thistle

  Echium plantagineum, Salvation Jane

  Erodium botrys, Long Heron's-bill

  Galenia pubescens, Galenia

  Heliotropium europaeum, Potato Weed

  Urtica urens, Stinging nettle

Transition indicators

State 6 transitions to State 7 or State 8, or State 9 if cleared.

Boundary indicators

B5 Loss of low nutrient soils. Significant increased soil nutrients, changed and cryptogams, and microbe diversity. Increased nutrient levels in soil favouring exotic species stops return to State 2.

State 7 – Nutrient enriched heavily grazed grassy woodland

Characteristics

State 7: Heavily grazed and with nutrient addition, understorey loss of tussocks and inter-tussock spaces, herbaceous weeds dominate

State 7 of the grassy woodland comes from State 6 over time, if the grazing pressure increases and regularly exceeds the carrying capacity of the site, or alternately comes from State 4 when nutrients are added by the heavily stocked animals grazing the site.

Management, impacts and disturbance

Grasslands in this State are likely to be managed for economic gain using stock grazing; however, the stocking rate is such that the system is not sustainable. This is common on the eastern flanks.

The combination of nutrients and over-grazing leads to a winter-boom biomass cycle, with winter annual grasses followed by baring of the ground in summer, as feed on offer declines to less than that required for the stocking rate. Non-palatable broad-leaved herbaceous weeds with a ground rosette dominate in summer, combined with a compacted soil where water run-off and erosion increases.

Native species that are resistant to heavy grazing and may be found include *Sida corrugata*, *Ptilotus spathulatus*, *Oxalis perennans*, *Convolvulus erubescens*, and *Chamaesyce drummondii*. The EPBC Act includes also *Maireana enchylaenoides*, but this may not be so.

There is more introduced annual biomass over winter / spring (>80%), followed by baring of the ground and dominance by non-palatable herbaceous species (*Erodium cicutarium*, *Arctotheca calendula*, and *Echium plantagineum*). This may continue into summer in those seasons with summer rains.

Perennial woody weeds such as Broad-leaf Cotton-bush *Gomphocarpus rotundifolia*, Horehound *Marrubium vulgare*, and African Boxthorn, *Lycium ferocissimum* are likely to occur.

Highly invasive non-woody perennial weeds are present such as Soursob *Oxalis pes-caprae*, Bridal Creeper *Asparagus asparagoides f asparagoides*. A few exotic perennial grasses (e.g. *Pentaschistis pallida*) may occur.

State indicators

- Increase in non-palatable species such as *Heliotropium europaeus*, Potato Weed *Romulea rosea* and *Moraea setifolia*.
- Native herbaceous species are almost all grazing resistant species such as *Sida corrugata*, *Ptilotus spathulatus*, *Oxalis perennans*, *Convolvulus erubescens*, *Chamaesyce drummondii*, *Maireana enchylaenoides*.
- Tussocks eaten down to tiny mounds and hard to distinguish
- Broad flat weeds with ground rosettes in winter and either some summer tolerant broad weeds or dusty paddock in summer

Winter

Arctotheca calendula, Cape Weed

Carthamus lanatus, Saffron Thistle

Cirsium vulgare, Spear Thistle

Echium plantagineum, Salvation Jane

Erodium botrys, Long Heron's-bill

Urtica urens, Stinging nettle

Summer

Arctotheca calendula, Cape Weed

Galenia pubescens, Galenia

Heliotropium europaeum, Potato Weed

Transition indicators

State7 transitions to State 8 with an overgrazing regime that promotes non palatable perennials or State 9 if cleared.

Boundary indicators

B7a Lost many small or delicate native species, loss of competitive ability of remaining natives, and lost habitat and soil structure. Significant loss of inter-tussock structure stops return to State 6.

State 8– Perennial weed dominated grassy woodland – nutrient enriched

Characteristics

State 8: Overgrazed and nutrient added, non-palatable species left, tree decline and death, no shrubs

State 8 is derived from States 6, and 7 in a similar way to that for State 5. The appearance may be similar to State 5 but with the transition through nutrient enrichment, the weed diversity, abundance, and biomass may be even greater. More importantly, the management history will mean that State 8 is likely to have less native grasses, geophytes and less diversity in the `native seed bank than State 5. The restoration pathway for this state will be more challenging than for State 5.

Management, impacts and disturbance

Management is similar to State 7a but there is an additional nutrient burden in the soil.

State indicators

- Presenting weed species similar to State 7a
- Fewer native species than State 7a

Transition indicators

State 8 is an end state unless it is actively managed for weeds or transitions to State 9 if cleared.

Boundary indicators

B7b Loss of most indigenous species except most grazing resistant, hardy, tall perennials. Loss of overstorey age dynamics. Domination by highly competitive exotic perennial grasses & perennial-rootstock forbs stops return to State 6 or State 7.

State 9 – Regularly ploughed ex-grassy woodland

Characteristics

State 9 can transition from most or all other states. It is grassy woodland where native species are no longer present. There will be use of fertiliser plus semi-regular cropping and also using broad-leaf +/- grass herbicides. Sometimes the cropped stubbles will be grazed. Sometimes the stubble will be burnt to remove snails. Regular ploughing will degrade the soil profile.

Management, impacts and disturbance

- Cropped with exotic grains, rapeseed (canola), or legumes

State indicators

- No residual grassy woodland species present
- No residual on site seed bank or other propagules

Transition indicators

State 9 is an end state unless it is actively revegetated for conservation and is restored to State 12.

Boundary indicators

B9 Loss of all species and community, loss of reproduction capacity, soil structure, and structural integrity stops return to any other State.

State 13 Unknown changes wrought by climate change.

State indicators

Long term change in weather patterns

Transition indicators

Unknown

Restoration Pathways

Restoration requirements for grassy woodlands

Remnant Mallee Box grassy woodlands, regardless of State, require a similar range of management actions.

Priorities

The priority for restoring this system is to manage the weed biomass (in particular annual species), deplete elevated soil nutrients, establish the ground layer first, promote any and all existing native species and undertake limited replanting after these are completed.

Native grassy woodlands are characterised by a short-lived seed bank. However, there is a (sometimes long) lag time before species are completely lost under inappropriate management. There are often long-term regeneration propagules not visible under the ground (rhizomes, corms, stolons, bulbs). For example, *Arthropodium strictum* can exist for many years even if it never produces a successful flowering stalk and fruits, by regeneration of the bulb by leaf growth. Studies have shown that most of the perennial species (native grasses and forbs) are not present in the seed bank and rely on a long-lived vegetative biomass to persist (Morgan, 1998). Therefore, once these plants have been removed through senescence, clearance or death resulting from over-grazing they cannot recolonise other than through active revegetation. This limits the ability of grassy woodlands to recover completely from disturbance, and also limits what can be achieved through restoration activities.

Where stock grazing has not been part of the historical management regime, the introduction of grazing should be avoided as stock can introduced weeds and nutrients. Where grazing has been part of the previous management regime, the complete exclusion of stock by fencing is likely to cause further degradation as non-indigenous species out-compete native species and become dominant. Therefore, a grazing regime that promotes native species and reduces the prevalence of introduced species is required. A window of opportunity exists here. Management can take advantage of the different growing seasons of native and weed species: the active growth period for native grasses is late spring to early summer when they set seed. Conversely, the active growth period for annual weeds is autumn to late winter. Light, continuous grazing results in the loss of palatable species, due to selective grazing. A high intensity / short duration regime, preferably after native plants have set seed and when annual weeds are actively growing is recommended (Barlow, 1998).

As discussed above, studies have shown higher concentrations of available nitrogen in topsoils where annual exotic species dominate (Prober *et al.*, 2002, 2005). Successful restoration requires taking actions to deplete soil nitrates and reduce exotic species abundance.

It is important to note that none of the following methods are reliable broad acre field technologies at this stage. Methods for achieving this are in development and some examples which have been trialled, with varying results, include:

- Removal of exotic grass biomass while actively growing, at the production of flower tillers and before seed set through crash / pulse grazing (as discussed above), appropriately timed slashing (Davies, 2000), or careful use of grass-specific herbicide use (Davies, 2000). The latter two techniques will result in a large amount of dead material which must be removed from the site or a dense thatch will be created which will release nitrogen back into the soil and reduce germination of inter-tussock species.
- Managed burns undertaken with care may assist in this process. It is important that careful calibrations about the timing of the burning are undertaken yearly relating to variable rainfall and balance between winter annual grasses and summer growing native grasses. Spring burns are often impractical. Late summer or autumn burns may not reduce annual grass seed but it may reduce the competition pressure of the annual grasses. Burning may reduce the density of exotic annual grasses but it can also increase perennial weeds. For example *Romulea rosea* and other broad-leaf annual weeds were found to increase following fire (Prober *et al.,* 2004, 2005). Spring burning is only likely to succeed if sufficient native species propagules exist to replace weeds (Prober *et al.,* 2005).

- Addition of carbon (e.g. sawdust) to the system to stimulate soil microbes which absorb nutrients (Prober *et al*., 2002). A trial of his technique by Prober, *et al.* (2005) found carbon supplementation reduces soil nitrates and exotic species growth in the short term, which may provide a window of opportunity for re-establishment of native species through germination of re-introduction;
- Scarifying or removal of topsoil to remove weed seed-bank and nutrient-enriched soil. This is only appropriate where native species are largely absent from the system. Due to the short-lived nature of native species' seed in the soil, this technique will not reduce likelihood of native species re-establishment. Re-planting or sowing of native species will be required.
- Re-establishment of native perennial species through replanting or sowing of seeds.

Where perennial introduced species (grasses, forbs, climbers) have become established, minimal disturbance weed control techniques such as spot spraying or grubbing will be required.

It is not possible to be prescriptive about restoration due to the variety of site- and season- specific factors that will influence the success of such activities. Furthermore, restoration trials can produce unexpected and undesirable results. Therefore, any potential restoration activities must be conducted in an adaptive management framework.

It is important to note that tree planting, although easy, is not always the best broad acre technique if not undertaken well.

Restoration of the tree layer in grassy woodland can restore the structural diversity quickly. Studies (xxxxxx ADD some examples) have shown an increase in abundance and diversity of birds increases soon after the trees are established. However, it is important to stage this to get the appropriate age dynamics.

If the Eucalyptus woodland originally had trees at 10-15m centres and each tree lives for 200 years, then only 4-5 trees per hectare per year over a 25 year period in areas managed for conservation are required to be actively established. For Sheoak woodlands where there were originally trees at 5m centres, and each tree lives for 80 years, then only 8-10 trees per hectare per year over a 20 year period in areas managed for conservation are required to be actively established.

Studies (xxxxxx ADD some examples) have shown an increase in abundance and diversity of birds increases soon after the trees are established. QUESTION how soon?? Does the density matter?? When does the whole suite of birds return??

State 10a – Restored grassy woodland

Characteristics

TOP State 10a via State 2 (left) shrubs regenerating and state 3 (right), annual grasses present but trees beginning to naturally regenerate.

BOTTOM State 10a via State 2 (left) shrubs regenerating and state 3 (right), perennial grasses and Acacia beginning to naturally regenerate.

State 10a comes from State 2 or 3 as a result of a change in management towards long-term conservation.

The native species composition will be less than for an intact remnant grassy woodland but there is sufficient diversity and abundance of native species that, when managed, it forms a good addition or buffer to intact remnant grassy woodland and is an essential component to maintain the grassy woodlands and its fauna in the system.

Although there are little data from the eastern flanks, management of an ex-farm of 100 years use in *Eucalyptus microcarpa* Grey Box grassy woodland on the western flanks has seen an improvement in native species from 25 native species in 1960 to 169 native species in 2010, a 7-fold increase over 50 years. (Robertson 2010)

Management, impacts and disturbance

Farming practices such as regular grazing are stopped and land is actively managed for conservation. Strategic biomass reduction techniques are introduced for biodiversity purposes; that is, time-managed grazing and / or slashing to favour natives. Active weed management of perennial weeds is also occurring.

State indicators

- Depauperate intact grassy woodland which has lost (mainly) inter-tussock species through past management practices
- Lack of some native herbaceous species
- Native grasses, Irongrass, small chenopod shrubs, and medium shrubs flower and set seed
- Evidence of active conservation management
- Active weed management of perennial weeds

Restoration pathway

State 10a is the best possible substitute for a State 1 habitat. It comes from State 2 with time and management of grazing and minor weed control, State 3 with management of excess biomass from annual grasses, State 5 with spot management of woody weeds and excess biomass from annual grasses, and State 4b with time and minor weed control and sparse addition of tubestock of trees. Direct seeding is inappropriate in all of these and tree and shrub planting is rarely required except in State 4b.

State 10b – Restored species poor grassy woodland

Characteristics

State 10b: Tubestock regeneration of trees and shrubs (top left), direct seeding of shrubs (bottom left) and natural regeneration of trees (right). Very little abundance or diversity of understorey exists.

State 10b is being recovered from other non-nutrient enriched States that are not able to be transitioned to State 10a. Native grassy woodlands rely on long-lived above-ground biomass for persistence and, other than annuals, the seed bank is short-lived. Therefore, once plants are lost from the ecosystem they cannot re-establish.

Similar to above, the site is now being managed for long-term conservation. These may look quite weedy for a few years and will have lower native species diversity as a result of past management practices.

State 10b may also come from State 10a as a result of inappropriate conservation management practices such as broad-acre spraying and direct-seeding of shrubs and trees, that leads to further native species loss.

Management, impacts and disturbance

Farming inputs of regular or continuous grazing cease and land actively managed for conservation. Biomass reduction techniques are introduced for biodiversity purposes; that is, time-managed grazing and / or slashing to favour natives. Active weed management of perennial weeds will also have to occur.

Re-introduction of lost species may also be considered depending on local circumstances and viability.

State indicators

- Less native species than State 8a.
- Native grasses flower and set seed

- Evidence of active conservation management

Restoration pathway

State 10b is the second best possible substitute for a State 1 habitat. It comes from State 5 with time, careful management of perennial weeds, management of other annual weeds, strengthening of the native perennial grasses and careful addition of other natives over time, and similarly from State 4. Direct seeding is rarely appropriate in either of these and tree and shrub planting is rarely required except if the tree and shrub layer is absent.

NOTE: States 2, 3, 4a and 4b and usually 5 are easier to take through a transition to some form of 'restored woodland' than States 6, 7, 8, and 9.

State 11a – Restored nutrient enriched grassy woodland

State 11a: Trees and shrubs (milk container guards) being planted into degraded woodland. As Sheoaks and young *E. porosa* already exist as a seed source, management might better be directed to management of the ground layer weed biomass and planting a few shrubs.

Characteristics

State 11a is being recovered from State 6 (grazed grassy woodlands with a high nutrient load and from which many native species have died out). The site is now being managed for long-term conservation. These may look quite weedy for a number of years after grazing stops and management to favour native species must be implemented.

Although there are little data from the eastern flanks, management of an ex-farm of 100 years use in Eucalyptus microcarpa Grey Box grassy woodland on the western flanks has seen an improvement in native species over a 50 year period, from 25 native species in 1960 to 169 native species in 2010. (Robertson 2010)

Management, impacts and disturbance

Farming inputs of regular or continuous grazing, and nutrient inputs cease and land actively managed for conservation. Biomass reduction techniques are introduced for biodiversity purposes; that is, time-managed grazing and / or slashing to favour natives. Active weed management of perennial weeds will also have to occur.

State indicators

- Less native species than State 10a with high nutrients and some weeds which are harder to manage
- Native grasses flower and set seed

- Evidence of active conservation management

Restoration pathway

State 11a is the third best possible substitute for a State 1 habitat. It comes from State 6 with time, manipulation of nutrient load (management of the ground layer weed biomass) careful removal of perennial weeds, management of other annual weeds, strengthening of the native perennial grasses, and careful addition of other natives over time. Direct seeding of trees and shrubs may be appropriate here to manage the weed burden and nutrient load. HOWEVER, this will usually require active heavy thinning of individuals and reshaping of trunks after several years to mimic the woodland structure.

State11b – Restored species poor nutrient enriched grassy woodland

Characteristics

State 11b is similar to State 10b except that it is derived via nutrient enriched pathways. It is the Recovery State for systems that cannot be transitioned back to State 10b.

State 11b may also be derived from States 10b as a result of poor conservation management practices that lead to further native species loss.

Management, impacts and disturbance

Farming inputs of regular or continuous grazing, and nutrient inputs cease and land actively managed for conservation. Biomass reduction techniques are introduced for biodiversity purposes; that is, time-managed grazing and / or slashing to favour natives. Active weed management of perennial weeds will also have to occur.

State indicators

- Less native species than State 10b with high nutrients and some weeds which are harder to manage
- Native grasses flower and set seed
- Evidence of active conservation management

Restoration pathway

State 11b is a poor substitute for a State 1 habitat. It comes from State 7 with time, manipulation of nutrient load (management of the ground layer weed biomass) careful removal of perennial weeds, management of other annual weeds, strengthening of the native perennial grasses, and careful addition of other natives over time. Direct seeding of trees and shrubs may be appropriate here to manage the weed burden and nutrient load.

HOWEVER, this will usually require active heavy thinning of individuals and reshaping of trunks after several years to mimic the woodland structure.

State 12 – Constructed grassy woodland

Characteristics

State 12: replanting (right) into paddock but spacing too dense, overstorey dominated.

State 12 may occur in the location of previous native grassy woodland but effectively no natural components remain. The community must be rebuilt from seeds, geophyte propagules, speedlings, and tube stock, along with water-transported, fauna transported and airborne propagules. Management can be undertaken to favour native grass species by grazing, slashing and / or burning. State 11 may transition from any other State. However, the success, rate of transition and final condition will be influenced by the previous management and in particular the nutrient and microbe composition of the soils.

State 12 may also come from any number of states following inappropriate revegetation work into various states of this community. The major indicator is the addition of trees and / or shrubs into the native Mallee Box grassy woodland, often for perceived conservation values.

State 12: Planting of *Eucalyptus globulus,* Tasmanian Blue Gum (left) and Olives (right) into degraded Mallee Box.

Management, impacts and disturbance

Management intended as conservation.

This is a grassy woodland mimic or surrogate community that is reliant on the propagation skills of the restorers as well as the availability of propagating material. The resulting structure and composition is heavily influenced by the perceived values of the day, but is likely to be limited to 20-30 species in the short to medium term. Shading from trees and shrubs in Lomandra grassland is likely to reduce the diversity of reptiles and may increase predation pressure by providing perches for birds (Schofield, pers. comm.).

This situation is quite commonly seen in lifestyle properties, hobby farms, and on various reserves being ‘amenity-improved’ by the landholder or by well meaning community groups. This can result in a new vegetation community when the spacing of plants and / or the choice of species and / or the source of seed can significantly change the Mallee Box grassy woodland structure and function.

For example, close planting of tree species can lead to upright trees without lateral branching, which are common in the spreading trees of Mallee Box woodlands, and which are important structural elements for some woodland birds.

State indicators

- Single age tussocks, in rows
- Shrub density too high
- Tree density too high
- Over-representation of large shrubs and trees, with little ground layer restoration
- Revegetation being undertaken
- Single age plantings
- Often over-representation of large shrubs and trees, with little ground layer restoration
- Trees and shrubs present
- Plants established in rows, individual plants planted too close together, plantings arranged in unnatural groupings
- Young trees and large shrub stratum species dominate
- Usually less than 20 species
- Very few ground stratum species planted
- Shrub variety and density too high
- Shrub distribution not strongly correlated to appropriate environmental factors

Restoration pathway

State 12 is a poor substitute for a State 1 habitat. It comes from State 9.

It may be that a good stand / sward of native grasses could / must be established before any addition of seed or tubestock of the trees, scattered shrubs and herbaceous species should be undertaken.

Explanations of the Model Diagram

Model transitions and threshold boundaries

Transition	Summary	Description
T1	Alter ecological processes	European use: fragmentation into blocks with a range of landforms (depressions and ridges); loss of native herbivores (particularly medium-sized marsupials); introduction of exotic herbivores (especially, rabbits, snails), and predators; loss of sensitive flora species and reduced reproductive output; change in fire regime; disruption of ecological processes (e.g., pollination of orchids); Nil or very infrequent & light production grazing, localised weed invasion.
T2	Introduce intermittent grazing	Regular light to moderate production grazing for economic gain without fertilisers or pasture species, usually but not exclusively in winter but also with long resting periods without grazing when water points dry up or stock moved to stubbles. Further fragmentation resulting in a reduced range of landforms in remnants, in particular weed-resistant, shallower soil areas. Native inter-tussock species decline, introduction of annual grasses, loss of cryptogams.
T3a	Introduce regular and/or heavy grazing	Heavy grazing in summer of patches when stubble in same paddock is grazed; Grazed in winter when adjacent areas fallow or in crop; development of adjacent areas for cropping increases fertiliser and weed drift.
T3b	Introduce regular and/or heavy grazing	Heavy grazing in summer of patches when stubble in same paddock is grazed; Grazed in winter when adjacent areas fallow or in crop; development of adjacent areas for cropping increases fertiliser and weed drift.
T4	Remove existing stock grazing regimes	Removal of existing stock grazing regimes, usually for (perceived) conservation or neglect / abandonment of previous management as land is now non-productive and/or stopped management when economic constraints prevail leads to weed invasion of aggressive perennial weeds and domination. Affected by time, source, and opportunity.
T5	Add nutrients and/or legumes to soil	Added fertiliser and passive addition of pasture species and increased stock rates as economic imperative to counter fertiliser costs or added nutrients in sheep droppings and urine; or infrequent application of fertiliser directly from plane or tractor; or indirectly as drift or drainage from adjacent fertilized cropped paddocks
T6	Stop active management of the area	Removal of existing stock grazing regimes, usually for (perceived) conservation or neglect / abandonment of previous management as land is now non-productive and/or stop management when economic constraints prevail leads to weed invasion of aggressive perennial weeds and domination. Affected by time, source, and opportunity. Nutrient levels boost weed competition.
T7a	Overgraze so perennial non-palatable species increase	Introduction / establishment of highly competitive exotic perennial species (e.g., *xxxxxxxxxxx* either deliberate (in the case of grasses) or accidental

T7b	overgraze so perennial non-palatable species increase	Introduction / establishment of highly competitive exotic perennial species (e.g., *xxxxxxxxxxx*) either deliberate (in the case of grasses) or accidental
T8	Remove tree layer	Loss of tree layer, especially Sheoak, when understorey still relatively intact (can occur from most states and for most understorey conditions)
T9	Clear several strata of vegetation	Clear, burn, plough, spray, introduce crops. Intensification of land use (Introduction of horticulture, peri-urban development, plantations, housing).
T10	Climate change	Unknown changes due to changed weather patterns

Boundary		**Description / result**
B1	Fragmentation	Interrupted and altered natural ecological processes due to European presence and influence. Loss of continuum in time and space.
B2	Lost grazing sensitive species	Loss species and propagules of grazing sensitive species; in this area mainly grazing-sensitive winter growing species, a few grazing resistant weeds invade and side effects of grazing
B3	Lost inter tussock space structure	Lost inter-tussock structure and excess annual grass biomass. Loss of species requiring open inter-tussock spaces. Addition of some weeds and some biomass accumulation
B4	Lost native species and structure	Loss of grazing sensitive species, Significant loss of annual and herbaceous species and changed habitat and soil structure and nutrient changes
B5	Increased soil nutrients	Loss of low nutrient soils. Significant increased soil nutrients, changed and cryptogams, and microbe diversity. Increased nutrient levels in soil favouring exotic species
B6	Lost openness of mid-storey structure	Lost openness of structure. Increased density of the low-, mid- and/ or overstorey reducing its value as woodland habitat
B7a	Lost species and structure	Lost many small or delicate native species, loss of competitive ability of remaining natives, and lost habitat and soil structure. Significant loss of inter-tussock structure.
B7b	Lost species and structure	Loss of most indigenous species except most grazing resistant, hardy, tall perennials. Loss of overstorey age dynamics. Domination by highly competitive exotic perennial grasses & perennial-rootstock forbs.
B9	Community lost	Loss of all species and community, loss of reproduction capacity, soil structure, and structural integrity
B8	Lost tree layer	Loss of tree layer, its resources, and its structural elements including fallen branches and loss of logs, regardless of the composition of the plant understorey. This renders it less suitable for sustaining birds and / or reptiles

Restoration	Summary	Description
R1	replace tree layer	Careful replacement of tree story only, at spacings (50m centres) and rates (10 per ha per 5 years) that help restore age dynamics, mainly in ex-sheoak woodland
R2a	manage annual grass biomass	Where grazing regime exists: Use of strategically timed pulse grazing and long resting periods to favour surviving native plant species and disadvantage most-competitive exotic species
R2b	manage annual grass biomass	Where grazing regime does not exist: Use of strategically timed slashing/grass-specific-herbicide/spot-spraying to favour surviving native plant species and disadvantage most-competitive exotic species
R3a	remove perennial weeds	Where understorey is relatively intact (such as invasion of pines into remnant vegetation) Careful removal of perennial woody weed species by herbicide spot-spraying, drill and fill, or other sensitively used method
R3b	remove perennial weeds	Where understorey has been significantly reduced in diversity and abundance: Careful removal of perennial weed species by herbicide spot-spraying, drill and fill, or other sensitively used method After period of time (5 years) reassess presence of natives and if and where necessary, addition of propagules of absent species, spot or broadcast seeding without herbicide or tubestock without herbicide.
R3c	remove perennial woody weeds	Where understorey has been significantly reduced in diversity and abundance and perennial weeds dominate Careful removal of perennial woody weed species by herbicide spot-spraying, drill and fill, or other sensitively used method Careful removal of perennial herbaceous weed species by herbicide spot-spraying, drill and fill, or other sensitively used method After period of time (5 years) reassess presence of natives and if and where necessary, addition of propagules of absent species, spot or broadcast seeding without herbicide or tubestock without herbicide.
R4	manage weeds	Manipulate soil nutrients if possible. Manage weeds so that native species are advantaged.
R5	manage weeds, add understorey species	Manipulate soil nutrients if possible. Manage weeds so that native species are advantaged. Addition of propagules of absent understorey species, spot or broadcast seeding without herbicide or tubestock without herbicide.
R6	manage weeds, add native species	Manipulate soil nutrients if possible. Careful removal of perennial weeds by herbicide spot-spraying, drill and fill, or other sensitively used method Manage weeds so that native species are advantaged. If missing, careful replacement of tree story only, at spacings and rates that help restore age dynamics. Addition of propagules of absent species, spot or broadcast seeding without herbicide or tubestock without herbicide.
R7	addition of native species	After R4, R5, R6 Addition of propagules of further (hard to propagate) absent species, tubestock without herbicide.
R8	rebuild community	Manipulate soil nutrients such as growing grass crops without fertilisers and remove biomass for several years. Broad-acre grass seed or densely replant grass speedlings. Once grasses re-established: Densely replant appropriate chenopod speedlings. Sparsely plant appropriate shrub speedlings. Plant trees at 50m centres and guard. Plant tubestock shrubs into re-established grass layer.

APPENDIX: Considerations for the Eucalyptus porosa (Mallee Box) STM for the MLR

Considerations for the Eucalyptus porosa (Mallee Box) STM low rainfall grassy woodland community of the Eastern Flanks of the Mount Lofty Ranges, South Australia compared to existing STM for the Mount Lofty Ranges/

What is different for this STM compared to others prepared for the MLR

- Lower rainfall at 300mm
- More summer rainfall and less winter rainfall (ratio different)
- Colder winter temperatures???
- More calcareous soils and duplex hard red earths
- Less impact from 'improved pasture' nearby
- Less nutrient load, less improved pastures with exotic perennial grasses
- Much lower diversity and biomass of woody weeds
- Few exotic perennial grasses, because of previous management history and lower rainfall
- Much larger areas seriously overgrazed over a long time
- More Themeda?? (visibly obvious March 2011) in grasslands areas with limited trees
- Large blocks and (until recently) low impact of sub-divisions of large blocks

Compared to *E. porosa* western side of MLR – along the Adelaide Plains close to coast)

- No influence of sea breezes
- Hotter summers
- Less winter rainfall
- Poorer (shallower) soils
- More area retained and in larger blocks

Compared to Lomandra grasslands of MLR

- Almost sympatric* with location of *Lomandra effusa* [grasslands]
- Very similar to *Lomandra effusa* grasslands but more important to manage with long rest grazing to let saplings survive, especially after years of higher than average rainfall
- Slight difference in understorey herbaceous species, not well defined
- Difference in biomass and presence of species of shrub species such as *Pittosporum angustifolium*, *Acacia menzelii* and range of other Acacia spp
- Sheoak woodlands seriously under-represented and present as (derived) Lomandra grasslands
- More shading and different water use with more shrubs and tree roots than in Irongrass grasslands
- Perches for birds allow for *Asparagus asparagoides* seed distribution
- Variation in the composition of the ground cover inside and outside the tree drip line of trees, which may be more weedy or less weedy in terms of biomass management, dependent on past management

(*describes species that occupy roughly the same area of land but do not interbreed)

Can we use the same STM model as *Lomandra effusa* grasslands, *Allocasuarina verticillata* woodlands or perhaps *Eucalyptus microcarpa* woodlands?

Indicator native species or weedy species are not the same

Amount and function of shrubs are different in the woodland versus grassland

Land use and land size different on western flanks woodlands

Woody weed biomass and variety less on western flanks

Serious widespread and long-term overgrazing more prevalent on eastern flanks

The *Eucalyptus microcarpa* woodlands are not considered to be a close enough comparison to use as a template.

Observations about the range of "looks" for the eastern flanks

Grass or ground layer: Lomandra on rocky ridges or lower rainfall to mainly perennial tussocks on higher rainfall, better soil

Understorey: Senna and small chenopods (Enchylaena etc) on low rainfall up to Dodonaea and Bursaria on higher rainfall.

Rocky areas with Astroloma humifusum

Tree storey: Some pure stands of *E. porosa* but also a mixture of Eucalyptus in the Bondleigh / Rockleigh area

However, as Boomsma and Specht say that the ecotones are wide and co-exist, I think we might combine *Eucalyptus porosa* woodlands, *Allocasuarina verticillata* woodlands and *Lomandra effusa* grasslands. *Allocasuarina verticillata* woodlands and *Lomandra effusa* grasslands in particular may look essentially the same and almost all of the *Allocasuarina verticillata* woodlands will now look like *Lomandra effusa* grasslands derived from *Allocasuarina verticillata* woodland.

In terms of management of these communities by groups or individual landholders it will be important to identify what should be re-established and where for each of these, when it differs.

DENR and other data sets indicate that *Eucalyptus porosa* woodlands also almost always include the species of *Allocasuarina verticillata* and *Lomandra effusa*.

There are also likely to be larger area of very degraded *Allocasuarina verticillata* woodlands and derived *Lomandra effusa* grasslands which will be more difficult to restore.

APPENDIX: Variation in the Communities included in this State Transition Model

E. porosa woodland over Lomandra, forbs and perennial grasses, limited shrubs, on flat ground – clay or calcareous earths

E. porosa and occasional *E. leucoxylon* over grasses and scattered shrubs, flat ground – sandy clay

Mixed woodland of *E. porosa* and *E. odorata* with *Allocasuarina verticillata* and occasional *E. leucoxylon*, quite dense, quite shrubby, hilly, some emergent rocks

E. porosa with Drooping Sheoak and Native Pine, undulating land, some emergent rocks, ephemeral creeklines

Sheoak over Lomandra and Bursaria, flat ground

Sheoak over Acacia paradoxa and native grasses, rocky ground

Mixed native perennial grassland: *Lomandra effusa, Aristida behriana, Themeda triandra* on clay soils

Mixed Themeda and Aristida grassland, rocky slopes