ERIC

SHRUB ENCROACHMENT IN WOODLANDS

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2008

Key words: Land degradation, Woody regrowth, Shrub invasion, Predictive modelling

Abstract

Around 40 years of observations are summarised to identify how woodlands develop and function, and how they respond to land use impacts. Key deficiencies in knowledge are identified.

Introduction

This summarises personal findings on shrub encroachments in semi-arid grazing lands based on around 10 years of field research and 25 years of general observations and consideration. The main research site was in poplar box woodland near Talwood in southern central Queensland. Much of the relevant information is given in papers on the ERIC web site.

The initial experiments established by Milton (RM) Moore involved tree thinning with and without grazing by sheep in poplar box woodlands. The grazing was implemented using intermittent high stocking rates. Tree thinning was by basal injection of picloram such that all trees boles remained insitu and there was no soil disturbance. Other experimental plots initiated around the same time involved complete killing or removal of trees combined with grazing. A later experiment investigated nitrogen mineralisation and soil and plant water relations with the killing of trees in poplar box and brigalow.

The experimental treatments included fire but the results were limited by the inability to burn grazed plots. The best observations on fire came from the burning of cleared areas containing abundant shrubs on an adjacent property.

The grazing experiments were established at the end of a severe drought that had effectively produced completely bare soil. Grasses were absent and acacia and cassia plants had died. Effectively the only live plants were poplar box trees and shrubs of Eremophila spp.

The different experimental treatments produced a diversity of forms of vegetation. These were opportunistically used to investigate the impacts of tree killing and grazing on the system, the interactions between trees, shrubs and grasses in vegetation development, and tree recruitment into the poplar box woodland.

Desertification through Grazing

This research direction arose from the observation that, in grazed woodland, sparse grasses occurred under tree canopies but not in the gaps between trees. The soil in gaps between tree canopies was bare. Trees are killed to increase the growth of grasses to improve grazing when grasses do better with grazing when under tree canopies than in the open.

From these observations it was clear that the issue of shrub encroachments related to the interaction between grazing and tree killing on the understory vegetation. Information on the separate effects of tree killing and grazing was obtained by sampling the surface soil and understory vegetation in areas subject to different treatments. The sampling gave the factorial design of trees killed, not killed; grazed, ungrazed. Effects of tree killing could be positive or negative for system function but all grazing impacts were adverse.

Following these observations a paddock containing poplar box woodland on a nearby property was observed to contain abundant grass with no bare patches. Moreover, there were few shrubs, and the shrub species present were not associated with shrub encroachments. This paddock had only ever been lightly grazed.

The general conclusion was that the shrub encroachments represent desertification caused by grazing. The effectiveness of rainfall is decreased by soil compaction increasing the surface runoff. From an ecological perspective, grazing has caused the boundary of the natural shrub woodland belt to move eastwards into areas naturally having grassy woodlands.

The only local data quantifying the increase in runoff due to grazing were measures of water penetration into soils obtained when investigating the separate and combined effects of grazing and tree killing. However, general observations support the suggestion that grazing increases runoff. For example, the extent of brigalow and associated gilgai soils has been increasing in run-on areas, as identified by Herbert (reported by Isbell[1]) and observed personally. Increased surface runoff does not necessarily increase stream flows as most of the additional runoff can collect in local depressions such as gilgaied soils.

Native grasses in areas subject to shrub encroachment are summer growing when in summer much of the rainfall arises through intermittent storms. The potential for runoff to modify grassy vegetation is high. In particular, storms provide the continuity of rainfall required for plants to survive. Grasses are therefore disadvantaged on runoff areas, but are promoted on run-on areas. Run-on areas with intact native vegetation remain grassy and relatively shrub free regardless of the level of grazing and the fire regime throughout all regions containing shrub woodlands.

Alternate explanations proposed for the shrub encroachments include a lack of fire, and grazing has been proposed as a means of control. When applied experimentally these treatments produced changes but did not ‘control’ shrubs despite extraordinary management measures. In studies elsewhere hay was imported to provide fuel for fires because of the limited grass growth, and goats meant to control shrubs died because of a lack of food. Control of shrub development was achieved with intermittent high levels of grazing by sheep at Wycanna but at the expense of increases in bare soil and soil compaction, and large reductions in grasses and forbs.

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[1] Isbell, RF 1962. Soils and vegetation of the brigalow lands of eastern Australia. CSIRO Aust. Soils & Land Use Ser. No. 43

Fire

Fire can modify vegetation, sometimes dramatically. However, the significance of fire depends on the characteristics of the fire and the conditions following the fire as well as the susceptibility of component species to burning.

Species in arid lands have evolved in the presence of fire hence all have mechanisms for surviving fires. Some survival mechanisms promote the survival of existing plants, with others the existing plants are killed and the species survives through the germination of seed. There is a great diversity of survival strategies and mechanisms. This interacts with the inherent variability in fires to produce a diversity of impacts. The variability in weather following the fire further adds to the diversity that can be achieved with the outcomes realised from burning.

With grazing sufficient fuel to propagate a fire effectively only occurs following abnormally wet conditions. Burning the pasture may then provide benefits in removing rank grass and killing shrubs, or suppressing shrubs such that they remain accessible for grazing. However, the direct cost is the loss of considerable organic matter that could be more beneficially used in improving the soil. The indirect cost of burning is soil exposure and a consequent increase in soil compaction. Rank vegetation in grazing lands should be slashed rather than burnt.

The question as to whether such burning would control shrubs cannot be simply resolved. The only simple answer is that it depends on a number of factors none of which can be well controlled. The outcomes from burning have high uncertainty wherein shrub numbers could increase or decrease. The only general conclusion is that fire degrades systems by promoting the loss of resources built up by vegetation.

Effective propagation of fire depends on the weather, particularly the humidity and wind. However, it also depends on the continuity of fuel. In open vegetation, such as areas used for grazing, a reasonably continuous cover of upright grasses is needed for fires to propagate. This arises because fuel effectively only ignites when heated by flame. The fuel elements have to be sufficiently close for the flame from a burning element to contact an unburnt element.

This need for contact by flame is a prime reason for the pronounced effect of wind in accelerating the propagation of fire. Wind effectively reduces the gap between fuel elements by increasing the projection of flame into unburnt vegetation.

This mechanism for fire propagation produces a constant rate of fire spread for constant fuel and wind speed, and this arises under experimental conditions. However, with extreme weather fires can keep accelerating rather than progressing at a reasonably constant speed. This arises through spotting by flaming embers and explosion of volatile compounds released from plants. Both factors result in fire leaping forward in episodic bursts.

Upright grasses provide the most effective arrangement of fuel for fire propagation because of their fineness, and because the area of ground affected by a burning element increases with the height of the fuel. Fire hazard can therefore be reduced by altering the type and arrangement as well as abundance of fuel.

Around 45% of the above ground organic matter is utilised by livestock with intense grazing of improved pastures in small paddocks. The amount of herbage grazed in woodland pastures would generally be appreciably less than 10% because of the type of pasture and the size of paddocks. Fuel loads cannot be significantly reduced through consumption of herbage by livestock. The occurrence of fires therefore cannot be significantly decreased by the consumption of herbage by livestock. This is reinforced by fuel loads only being adequate for fire propagation during periods of abundant pasture growth.

Livestock increase the lodgment of grassy fuels through trampling where this would directly and indirectly reduce the fire hazard. The direct effect relates to reduced propagation of fire between fuel elements. The indirect effect relates to the increased rate of breakdown of litter lodged on the ground compared to when it is upright.

While these effects are significant in reducing the fire hazard the greatest effect likely arises through reduced grass production. That is, the amount of fuel is greatly reduced through the negative effects of grazing on grass growth. Grazing typically reduces the fire hazard but in a manner that damages the system.

Fires are commonly intentionally lit to reduce the risks associated with high fuel loads in extreme weather conditions. Also, fuel reduction burning was almost universally conducted on northern cattle properties to remove rank hamper and promote the growth of nutritious green pick. Burning can provide large benefits as stock loose weight coming out of winter through the low nutrition of the senesced grasses. Such fires are lit under mild conditions to produce low fire intensities.

Such intentional burning was previously conducted in spring when conditions promote the rapid regrowth of vegetation. Indeed, for grazing fires were only lit following rainfall to ensure the rapid regrowth of grasses. However, it is now common for fires to be lit in autumn when in most of Australia conditions are unfavourable for the growth of most native plants.

Burning in autumn in southern regions is particularly damaging to perennial plants as most cannot regain foliage until spring, initially due to dry soils and then low temperatures. Many plants do not survive over winter. While this may appear to address the requirement of shrub control, any gains are small compared to the losses arising through other impacts. Perennial grasses and herbs are suppressed as these are generally summer growing. There is strong promotion of winter annuals, many of which are introduced weeds. It also increases the amount of bare ground. Graziers in northern Australia have intentionally used late season fires to degrade native woody vegetation in the mistaken belief that any damage to woody plants benefits their livestock.

The appropriate time for hazard reduction burning is when plants will actively regrow, and this was done with Aboriginal land management. The prime purpose of burning was to increase safety, but it was also used to draw animals into patches of green pick to facilitate hunting, and to produce conditions favourable to harvested species.

The appropriate season for burning varies across Australia due to differences in the seasonality of rainfall, and hence the growth patterns of vegetation. Burning is best conducted in late winter / early spring in most regions, but autumn is most appropriate in monsoonal climates.

In northern Australia fires are lit as soon as possible at the end of the wet season when there is sufficient soil moisture for the vegetation to rapidly regrow. Burning at the end of the dry season fells mature trees because of the extreme dry conditions, and makes the soil vulnerable to severe erosion with the intense storm rains.

Fire is generally not an appropriate tool for producing particular forms of vegetation as the realised changes cannot be reliably predicted. One reason is that plant responses can depend strongly on seasonal conditional conditions following the fire. Another is that fires are innately highly variable in how they burn, and hence in the associated impacts. However, the key reason is because the long term consequences may not be evident from observations of the effects of a few fires. Fires degrade the vegetation hence the effect can be analogous to grazing. For example, regular burning can convert natural grassland into shrubland as occurs with grazing. The damage to soils is the same as with grazing in involving compaction and a loss of nutrients and the capacity to store water.

Burning is necessary to reduce fire hazard, and because many Australian plant species depend on fire for regeneration. Fire is essential for many forms of vegetation. Burning is therefore commonly necessary, but it must be managed to address the needs of the vegetation rather than the convenience of managers and administrations. Frequent regular burning is damaging, particularly if the vegetation is burnt when conditions prevents its rapid recovery.

Fertility

The soils are sedimentary with the materials identified as arising through weathering of the Great Dividing Range around 100km to the east. The materials are highly weathered and the soil is underlain by a thick layer of essentially pure kaolin. This has low levels of nutrients and a low capacity to adsorb nutrients. Kaolin is the final stage in the weathering of clay minerals.

The loamy surface soils are red due to iron oxides but the light to medium clay B horizon is pale due to the abundance of kaolin. The B horizon has a columnar structure due to fracturing arising from wetting and drying. Soil samples obtained down a crack indicate a gradational soil profile but sampling a column identifies that the soil profile is strongly duplex. The thickness of the A horizon is around 0.2m but varies considerably with position in the landscape and the impacts of land use.

The inherent fertility of the soils is low given the weathered nature of the material. Moreover, the potential of the mineral soil to store nutrients is very low because the clay is kaolin. The fertility of the soil depends strongly on the accumulation of organic matter.

The significance of organic matter for soil fertility is evident in the natural patterns of vegetation. Soils made dark through the accumulation of organic matter support brigalow and/or belah where these communities maintain a much greater level of foliage than poplar box. When cleared the grasses are more nutritious on the grey brigalow and belah soils than the red poplar box soils. The differences in fertility are clear in soil chemical analyses.

Brigalow and belah typically occur in run on areas of the landscape and so can have higher accessions of water than poplar box. They also accumulate sediments from upslope. The pattern of treed vegetation is therefore generally attributed to patterns of soils which is linked to topography. However, soil samples obtained from around different plant species identified that the patterns of nutrient availability relate mainly to the vegetation. The fertility of the soils is much more a consequence of the vegetation than vice versa.

The dependence of soil properties on vegetation can be observed where brigalow plants recruit on the lower slopes in areas of poplar box. The soil associated with clusters of young brigalow plants has obviously higher levels of organic matter than around poplar box trees.

The mineral materials in all soils derive from the same source thus differences between soils can only derive from effects of topography and vegetation. While there is an interaction between topographic position and vegetation in soil development, vegetation has greatest effect on soil fertility.

An apparently anomalous aspect of nutrient relations is that field levels of available nitrogen are much higher under poplar box than brigalow. This is despite brigalow being a legume with mychorrhiza, and the brigalow soil having much higher levels of total nitrogen and organic matter than with poplar box. However, when incubated in the laboratory the nitrogen mineralisation in the brigalow soil is much higher than for the poplar box soil. Patterns of nitrogen mineralisation for brigalow and poplar box soils in the laboratory are the reverse of that in the field.

This difference between laboratory and field results likely arises because the laboratory samples were disturbed, and hence had high aeration, while the field samples were undisturbed. Brigalow soil has higher clay content than the poplar box soil, and the dark colour arises from a lack of oxidation (hydration) as well as the accumulation of organic matter. The red colour of poplar box soils arises from iron oxides: the poplar box soil is highly oxidised and therefore well aerated.

The accumulation of organic matter under brigalow therefore arises through low rates of breakdown of organic matter than with poplar box as well as higher production. This pattern is widespread in western regions with loamy soils on slopes being light and/or red, and soils in gullies and other accession areas being dark.

This natural pattern of nitrogen availability has implications for agriculture. Appreciable grass growth only occurs on brigalow soils when the soil has been wet for a considerable period. Grasses on poplar box soils respond rapidly to even small rainfalls but they regress just as rapidly when the soils become dry. Fluctuations in nutrient availability on the aerated soil are large and rapid while fluctuations on the hydrated soil are low and slow. A key reason for the accumulation of organic matter in brigalow soils is poor aeration associated with hydration slowing the rate of breakdown of organic matter.

Poplar box soils are highly susceptible to adverse impact as the stores of organic matter are readily depleted. When the organic matter is lost so too is the ability to store nutrients, so these too are lost. The loss of organic matter degrades soil structure wherein soils become compacted and have reduced water infiltration and storage capacities.

Heavier textured soils are more resilient to land use impacts due to soil hydration. However, organic matter and nutrients are still lost at an excessive rate if the soil becomes aerated, as arises with ploughing. Exposing the soil to radiation further increases the rate of breakdown of organic matter by increasing soil temperatures.

The adverse impacts of land use on light textured soils can be rapidly reversed. Levels of soil organic matter in cropping lands can be rapidly increased from their current low level by not ploughing and applying diverse populations of microbes. This identifies the potential of the soils to accumulate organic matter if appropriately managed. However, the accumulated organic matter can be lost as rapidly as it was gained simply by disturbing the soil and/or damaging the vegetation.

This identifies that the desertification cause by grazing in poplar box woodlands is associated with decreased nutrient as well water availability. Redressing the adverse impacts of past land use therefore depends completely upon rebuilding the levels of soil organic matter, where this depends on removing impacts on the soil and supplying food for microbes via vegetation. It is essential that the soil profile is not disturbed and that there is always a good cover of vegetation.

Misinterpreted results

A classic paper on grass response with tree clearing derives from observations on poplar box communities. This identifies that virtually all trees must be killed for there to be a large growth response in grasses. These results have been taken to justify the removal of trees from grazing lands on the basis that grass production is greatly diminished by the presence of trees.

The result for grass response with tree thinning is similar to those for competition between crop plants in identifying strong competition. However, later results discussed below demonstrate a pronounced lack of competition between trees, shrubs and grasses. The likely reason for the observed large grass response to tree thinning relates to a boost in nitrogen mineralisation following tree clearing where this is caused by increased soil temperatures and increased levels of soil moisture.

Except for one measurement this boost in soil nitrogen availability with tree killing would have been statistically shown in a field nitrogen mineralisation study. However, as there was no apparent reason to reject the single extreme observation the results were not initially reported. However, the results were significant at the 90% confidence level used in medicine.

Individual high nitrogen readings can arise for a number of reasons, such as urination by a kangaroo. Also, the statistical evaluation of significance was strongly affected by the high fluctuations of nitrogen availability in the poplar box systems. From considerations of the process involved with nitrogen mineralisation the initial flush of grass growth following tree removal is likely due to a flush in nutrient availability due to the release of soil reserves. This suggestion accords with the observation that the flush of herbage growth following tree killing arises through existing plants getting bigger rather than recruitment.

The suppression of grasses by trees observed in the first few years following tree killing does not persist. It is essentially certain that the flush in grass growth following tree killing is associated with the initial impact. The large response in grass growth following the killing of trees is a transient effect that disappears when the reserves of nutrients are depleted.

The long term effects of tree killing and grazing are best identified by the survey studies on impacts of tree killing and grazing, and on vegetation development. Tree killing mitigates some impacts of grazing but exacerbates others. Tree removal does not continue to provide the benefits indicated by initial results from tree thinning experiments.

Observations of patterns of grazing by livestock indicate there is more to be learnt about the nutrient relations in woodlands. In an abnormally wet period at Wycanna the abundant grass in the cleared area was not grazed by livestock. The livestock only grazed in well treed woodlands. From the colour of their foliage the grasses in cleared areas had low nitrogen (they were rank) whereas grasses in the woodland had high levels of nitrogen. This pattern could relate to demineralisation in waterlogged soils but there are no observations to show that the grasslands were waterlogged.

This preferential grazing by livestock in woodlands was observed by the first settlers. On the Cumberland Plain livestock grazed under trees in preference to open grasslands. The first settlers used livestock to identify areas with highest nutrition.

The issue is why should grasses have higher nutrition when associated with trees, particularly when they are identified as competing with trees for nutrient and water resources.

Vegetation Development

Bengt Torssell and Tony Nichols compiled 10 years of detailed records on grass and shrub numbers obtained annually for the original tree thinning/grazing experiment. The expectation was that the long term development patterns of the tree, shrub and grass components would reflect those observed in crop studies where an increase in one component is associated with a commensurate decrease others. This pattern arose with the initial development of grass biomass with tree thinning but did not persist.

Most of the detailed observations of shrub and grass abundance addressed plant numbers but not biomass, and this limited the analysis. However, even when realistic transformations to abundance were made it was clear that the expected competitive interactions did not arise. This led to a survey based study investigating the relationship between the relative abundance of trees, shrubs and grasses.

The survey results on the interactions between the tree, shrub and grass components accord with the detailed observations in the experimental treatments. While there is a general tendency for the vegetation to cycle in the relative proportions of trees, shrubs and grasses the development of each component is largely independent of the others.

This apparently anomalous situation was subsequently observed in forests in central Sweden. While limits exist to the level of development of the vegetation, and for each component of the vegetation, these limits seldom reached.

A theoretical consequence of this apparent lack of competition between the vegetation components is that the vegetation does not occupy all of the available space. It is generally assumed that vegetation develops to a maximum commensurate with the available resources. It occupies all of the available space where the available space is set by physical constraints such as rainfall and radiation. However, the observed levels of development are usually well below the observed maximum. To realistically model the dynamics of the vegetation a fourth component must be identified, namely bare ground.

Bare ground identifies the extent to which the abundance of vegetation is below the absolute maximum. The results identify that the usual statement that vegetation expands to occupy the available space must be modified to vegetation **tends** to occupy the available space as full occupation is seldom realised.

The recruitment of seedlings is a key component of vegetation development but no detailed observations of recruitment were available for trees. I had observed that occasional seedlings of poplar box could be found at virtually any time in dense vegetation, particularly at the base of Eremophila mitchellii (false sandalwood). However, these seedlings never developed and hence were never recruited into the communities.

After a 20 year interval it was found that poplar box seedlings had recruited, and that their spatial patterns largely matched expectation. The scale of sampling when addressing vegetation composition was based on the observation that patches of poplar box trees tended to form copses where each copse comprised 2 and sometimes 3 cohorts of trees. The cohorts were discriminated by trunk diameters. Within a copse the tree trunk sizes occur in two or rarely three distinct size classes. The differences in trunk sizes between copses are usually smaller than within but they are usually distinct.

The hypothesis was that the tree density must decline to a low level before tree recruitment can occur. While tree seedlings could be observed at most levels of tree development substantial recruitment only occurred in areas with sparse trees. There was no indication of an effect of grasses and shrubs on tree recruitment.

While the density of existing trees had to be sparse for significant recruitment to occur no seedlings were observed on bare ground. Trees did not recruit where there was no potential for competition with other plants. This is despite a potentially abundant supply of seeds through wind and flood.

This episodic recruitment of trees means that the development of vegetation reflects the life cycles of the component plants. Vegetation develops and declines similarly to the growth and decline of individual plants. The mosaic of copses containing different cohorts of trees reflects a time-space equivalence as the spatial patterns arise from differences in plant age. The lack of occupation of space, or need to identify bare ground as a component of the system, is an inevitable consequence of episodic recruitment and plant life cycles.

The independence in the development of the tree, shrub and grass components additionally partly relates to the availability of resources for plants depending on the level of development of the existing vegetation. The availability of nutrients depends on soil microbes where the development of soil microbes depends on the level of development of the vegetation. This produces a positive feedback through the potential for development depending on the level of development. The resource availability, or available space, is not fixed but varies with the level of development of vegetation.

Without constraints such positive feedback produces unconstrained exponential growth. This does not occur because the availability of some resources does not depend on the level of vegetation development. Light, for example, presents an absolute limit to vegetation development. The realised patterns of development reflect the interaction between the availabilities of different resources and the life cycles of the component plants.

The positive feedback appears to operate independently for each life form. As a component of vegetation development does not involve competition between the different life forms, the tree, shrub and grass components each appear to be able to monopolise resources they produce. This is most clearly evidenced in the potential level of development of the vegetation increasing with the number of life forms. That is, the potential for the development of poplar box vegetation is greatest when trees, shrubs and grasses grow together. Mixtures of trees and grasses, or trees and shrubs, have higher development potentials than trees alone.

The apparent occurrence of separate resource pools associated with different life forms is an aspect of vegetation development evident in the results that cannot currently be explained. For nutrients the separate resource pools could be explained for species and individuals but there is no apparent reason for the separation to be associated with life form.

Observations in agricultural systems and forests identify that the availability of water increases with the development of vegetation. Vegetation appears to produce water additional to that obtained from rainfall but the associated mechanism is unknown. This provides a mechanism additional to nutrients where the availability of resources depends on the level of development of vegetation. However, acquisition of water can potentially be related to plant life forms.

Brigalow v Poplar Box

Brigalow and poplar box occur in the same environment and on soils derived from the same parent materials. However, the two communities have markedly different soils and vegetation. The differences between the vegetation and soils provide insights into the interaction between vegetation and the environment.

Brigalow typically occurs in run on areas, and poplar pox in run off areas, but this is not invariant. Considerable areas of poplar box occur in floodways while large areas of brigalow occur in areas that do not receive any run on.

Brigalow and poplar box communities tend to be monospecific in the tree layer. However, brigalow tends to exclude all other plants whereas poplar box communities always contain a mix of trees, shrubs and grasses. The proportion of grasses relative to shrubs decreases with both decrease in rainfall and increase in the coarseness of soil texture.

Brigalow can recruit within stands of poplar box and, where it does, the soils transform. Poplar box does not recruit within brigalow.

Brigalow can recruit as suckers as well as seed. Poplar box only recruits through seed.

Brigalow communities have around double the tree leaf area to poplar box, and the trees only drop old leaf in association with the development of new leaf. Poplar box additionally drops leaf when conditions become dry.

Brigalow phyllodes are flat, rigid and vertical. While the phyllodes are falcate, the tips can point upwards or downwards. Poplar box leaves are also vertical but are always pendulous. While the leaf surfaces tens to be flat they form smooth convex curves. Their shapes range from round to ovate.

Brigalow has very high density timber that is highly resistant to breakdown by fungi and termites. Poplar box trees are invariably hollow, and this is a genetic trait. The hollow trunks typically contain termite nests.

Brigalow communities are seldom subject to fire as the phyllode litter is fire resistant and there is little grass. Poplar box communities are fire prone due to grasses being naturally abundant.

The nitrogen store in brigalow soils is high but the availability is continuously low. The nitrogen store in poplar box soils is low but the availability is high following rainfall. Soil nitrogen availability is steady with brigalow but fluctuates markedly with poplar box.

Generalisations

The most obvious generalisation is that low diversity brigalow vegetation tends to be highly stable while the floristically diverse poplar box vegetation fluctuates markedly. The common suggestion that diversity confers stability is inapplicable. This suggestion derives largely from predictive models (Annex A).

The large difference in the amount of vegetation between brigalow and poplar box arises despite the mineral soil materials and climate being the same. It is an example of the level of vegetation development depending on the vegetation. The resource available to vegetation depends on the level of development of the vegetation.

The means by which brigalow vegetation develops to around double the biomass of poplar box is not completely clear. It appears to relate partly to conservatism wherein the breakdown of organic matter is slow compared to poplar box. However, it likely also partly relates to higher production in brigalow. The higher nutrient availability developed in brigalow vegetation allows for more efficient use of water.

The strategy employed by brigalow plants is to rapidly use water when it becomes available and to survive extended periods with highly restricted water availability. This is possible as the high nutrient status allows for efficient use of water starting from the initial rain drop. It is also made possible by the woody structure of brigalow phyllodes that provide for the development of very low plant water potentials. Even photosynthetic cells[2] have thick walls and small lumens.

The strategy employed by poplar box is to effectively change according to conditions. Abundant leaf can be produced during extended periods of good water availability but leaf is dropped during drought. The generally low leaf area means that water use is never particularly high. While this represents a competitive disadvantage by leaving water for other species it is likely a consequence of the dependence on soil nitrogen mineralisation.

Following rainfall it takes around 2 days before soil mineralisation provides a good supply of nitrogen for plants. There is therefore no benefit in rapidly using water from the first rain drop as the low nutrient availability limits the effectiveness of its use. The disadvantage of this slow use of water is that resources are readily available to other plant species.

The structural and floristic forms of brigalow and poplar box communities reflect two contrasting strategies. There is no doubt that brigalow is dominant provided it can survive. A critical issue therefore, is what factors limit application of the strategy developed by brigalow.

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[2] They are not the same as palisade cells in leaves but they perform the same function.

An obvious limiting factor when rapidly using water is the ability to survive extended periods without water. Brigalow occurs in climatically non-seasonal regions where significant rainfall can occur throughout the year and temperatures never prevent photosynthesis. However, while this explanation likely applies, it is undoubtedly incomplete. There are additional factors that aren't currently known.

Likely Scenario for Shrub Encroachment

Shrub encroachment appears mainly due to invasion by immigrant species rather than expansion in the populations of existing species, hence use of the term encroachment. The 'new' species emigrate from drier regions. The main invading species have moderately large, hard-coated seeds and are likely dispersed by large animals. Any such need for dispersal can affect species complement, and will slow the initial rate of invasion.

Grazing can have little effect on grasses in most years, but climatic fluctuations inevitably result in overgrazing through attempts to maintain livestock on the land during drought. Supplementary feeding by felling palatable woody vegetation and importing fodder exacerbate overgrazing.

Overgrazing denudes the soil resulting in a loss of organic matter and soil compaction. The bare soil provides opportunities for recruitment of many plant species but the reduced availability of water promotes the recruitment of emigrants from drier regions. As shrubs are abundant in the drier regions, and as many have characteristics that facilitate emigration, shrubs are a prominent component of the recruitment.

The vegetation may appear to recover from the initial overgrazing following good rains but shrubs become more abundant. Moreover, the regenerated system has lower resources than existed before the drought. Water availability is reduced due to soil compaction, and so too is nutrient availability due to loss of soil organic matter.

This cycle is repeated with successive droughts with the resource availability decreasing with each cycle. A critical point is reached when the resource availability is insufficient to sustain the recruitment of any plant species. The vegetation then develops large bare patches, and this situation is common in western NSW. Desertification is the final step in this progression.

Most areas subject to shrub encroachment now contain large seed pools of the invading shrub species, and low seed pools of the original perennial grasses. Disturbance of any form can therefore promote shrubs. Reversion to grassy woodland requires appropriate management to promote the rapid development of grasses such that they suppress shrub recruitment. This likely initially requires exclusion of grazing, and definitely requires that any ongoing grazing is strictly controlled so as to always maintain a good cover of ground layer vegetation.

Grasses have been successfully established in areas of completely bare ground, and in vegetation comprising bare ground and shrubs. Shrubs are removed using a blade plow and grass seed and fertiliser applied to the disturbed soil surface. As introduced grasses have been used there is a need to address the reintroduction of the original perennial grass species. Benefit would also be expected from other management options, such as applying populations of microbes along with the seed.

ANNEX 1

Predictives v Analytics

Models are commonly used to predict the future, and nowadays ‘scientific’ models almost invariably involve numerical computer simulation. The models arrange what is known in a numerical form where the arrangement by way of model structure relates to the availability of numerical methods as well as the availability of information.

Models are fundamentally abstractions that simulate reality. While they can simulate reality they can never emulate reality. Results from models are never real, and never can be. Predictions represent a best guess approximation based on the available information and the tools available to manipulate it.

The fundamental question with any prediction is, how reliable is it? The answer can never be known with complex systems such as vegetation as the model outputs can never be fully tested. The best that can be done with complex models is to test component parts. However, natural systems function through interaction. As not all interactions are known, testing the component parts does not evaluate the reliability of the model.

Predictive models represent descriptions of the system using numbers instead of words. While the use of numbers gives a semblance of science it does not address the most fundamental requirement of the scientific method, the requirement for testing. In being descriptive predictive models always give a result, but there is no way of knowing how reliable the result is.

Science is based on abstractions, hence models are central. However, not all models are subject to the extreme limitation of predictive models. The two forms of model most used to develop and hence progress science are conceptual and analytical.

Conceptual models represent the provision of a theory in a way that allows further examination. A conceptual model is a proposition rather than a statement of fact. They effectively provide a hypothesis that can be used as a basis for testing. A conceptual model may lead to predictions but the testing allows identification of the limits to any predictions.

Analytical models are structured to test hypotheses. In effect they provide a means of testing conceptual models. As with conceptual models they may lead to predictions but the testing allows identification of the limits to applicability.

The benefits of analytical modeling are the development of knowledge and provision of reliable generalisations that can be used in applications. There are no benefits with predictive modeling, but there are pronounced detriments. They give the semblance of knowledge but in doing so hide deficiencies. They therefore stall progress in science as well as providing spurious ‘information’.

This situation can be illustrated by the resource availability to vegetation depending on the level of development of vegetation and not solely on the physical environment. Existing models assume that vegetation development is constrained solely by the physical environment and hence produce incorrect results.

A conclusion that effectively derives from predictive models is that the stability of vegetative systems depends on their complexity. This arises because the stability of the models used depends on feedbacks, and the number of feedbacks increases with increase in complexity. However, the floristically and structurally simple brigalow community is much more stable than the more complex poplar box community. Moreover, the leaf area and biomass are considerably higher in brigalow. Simple brigalow vegetation develops to a greater level and is much more stable than the complex poplar box vegetation. Application of predictive models has resulted in incorrect conclusions.

The key reason for incorrect conclusions using predictive models is that the outcomes are a function of the model structure. Without testing there is no way of knowing the extent to which the results reflect the structure of the model compared to the information fed into the model. The results can be dramatically wrong, as with the conclusion that stability depends on complexity, but without testing there is no way of identifying and correcting this fundamental error.

The error in identifying stability as depending on complexity has widespread implications for applications. For science it has resulted in the wastage of effort in pursuing lines of research that are at best unproductive, and at worst compound the initial error.

When it comes to science analytics can have a win and move on to the next round but predictives never can.