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Effect of stock removal on woodlands in the Murray Mallee and Wimmera Bioregions of Victoria

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EFFECT OF STOCK REMOVAL ON WOODLANDS IN THE MURRAY MALLEE AND WIMMERA BIOREGIONS OF VICTORIA

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FURTHER INFORMATION

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SUMMARY

In the Murray Mallee and Wimmera Bioregions there is little native native vegetation remaining in the landscape. Remnants typically exist as small, isolated patches in the wheat and sheep farming zone and are grazed by stock for a few months every one to three years.

In order to achieve an increase in native vegetation cover at the landscape scale, in addition to regeneration and revegetation, even small and relatively degraded remnants need to be maintained. Can they recover ecological function and have some hope of persisting if grazing pressure from domestic stock is removed?

This report describes a survey of 20 native vegetation remnants (<30 ha) in semi-arid woodlands where stock have been excluded for up to 50 years before the present. We assessed biophysical data including regeneration of woody species, biological soil crust cover and soil nutrient levels as key indicators of the ecological function of sites. Interviews were also conducted to understand the history of remnant management.

We established that some aspects of ecological function return relatively quickly, but others are far less resilient:

- After 15 years, the total cover of biological soil crusts increased to levels comparable with data from some of the least disturbed public land remnants in the area.
- Morphological group diversity of biological crusts takes much longer to re-develop
- Recruitment in Buloke, Black Box and Mallee woodlands is greater in sites where stock has been excluded for longer; indicating that time alone is enough to stimulate regeneration of at least some woody species once stock pressure is removed.
- Buloke (*Allocasuarina luehmannii* (R.T. Baker) L.A.S. Johnson) recruited frequently, probably through suckers and seeds, whereas recruitment in Mallee woodlands was far less frequently observed.
- Available soil phosphorus was not related to time-since-grazing indicating that once enriched; remnants may remain enriched for decades.
- Annual weeds occupied less ground space in remnants without stock for longer periods, indicating that some transition is possible even while additional soil nutrients remain.

Only the passage of time can confirm whether these small degraded remnants will remain viable into the future. However, our data show that some encouraging improvements can occur in even heavily degraded remnants once stock grazing and stock camping pressure is removed.

We conclude with recommendations for native vegetation protection and grazing management that we believe are appropriate for the remnants in Murray Mallee and Wimmera Bioregions of Victoria. Landholders should be encouraged to provide for regeneration opportunities within all remnants if possible, even where ongoing use for stock shelter or feed is anticipated.

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INTRODUCTION

The dryland cropping landscapes of the Murray Mallee and Wimmera Bioregions are some of the most “stressed” landscapes in Australia (NLWRA 2001) as a result of a long history of extensive and intensive use. The majority of native vegetation was cleared for pastoralism and agriculture between about 1840 and 1940 (Blakers and Macmillan 1988; Land Conservation Council 1989) and native vegetation cover over large areas is as low as 5%. Remnant vegetation in these landscapes usually exists as small, isolated patches, often under considerable management pressure from stock grazing (Duncan et al. 2006).

There is an urgent need to increase native vegetation cover and quality in the Murray Mallee and Wimmera Bioregions to protect landscape health and the habitats of flora and fauna. The task is not a simple one, as there is a range of landscape and local threats that are acting on remnant vegetation (Dorrough and Duncan 2006; Duncan et al. 2006). Nevertheless, Catchment Management Authorities have a responsibility to improve the extent and quality of native vegetation in these bioregions under the *Catchment and Land Protection Act 1994*. These responsibilities contribute to the overall goal of net gain in native vegetation condition (Department of Natural Resources and Environment 2002).

A broad survey of remnant vegetation in the Murray Mallee and Wimmera undertaken in 2005 (Duncan et al. 2006) identified threats and degrading processes affecting remnant vegetation. The study identified substantial degradation and dysfunction in small remnants in particular. These have high exposure to influences from adjacent land use. Small remnants are typically nutrient enriched, have few native species, and lack regeneration of the remaining perennial woody species (Duncan et al 2006b). Larger remnants (>100 ha) had better ecological function, having more stable soils, fewer weeds and more regeneration. Remnant size can be important of itself because of edge effects, which swamp the smallest remnants. Remnant size is also related to long term grazing pressure. The study concluded that degradation of small private land remnants threatened their survival beyond the current generation of trees that identify them.

Landscape restoration is as expensive as it is urgent (Vesk and Mac Nally 2006) and must take place within the context of available resources. Triage has been promoted as an appropriate model to guide where vegetation enhancement activities should be allocated (Hobbs and Kristjanson 2003; Dorrough and Duncan 2006), whereby small, highly degraded remnants ought to be a last resort for investment. In the Murray Mallee and Wimmera Bioregions, however, substantial gains in landscape cover will require assisting degraded vegetation to recover and regenerate, and require considerable active revegetation of cleared areas. But what is the capacity of such remnants to recover when key threats such as stock grazing pressure are removed?

Grazing from domestic stock is known to have profound effects on the ecology of native vegetation remnants (Pettit et al. 1995; Yates et al. 2000; Spooner et al. 2002; Lunt 2005). Stock pressure comprises grazing and browsing (removal of plant biomass, prevention of formation of reproductive tissue), trampling and compaction (soil desiccation, destruction of seedlings, exposure and desiccation of young root networks, destruction of soil bio-pores, break up and loss of litter layer, degradation of soil invertebrate habitat), and camping (concentrated deposition of urine and faeces and feed provision, intensive physical disturbance, rubbing and ringbarking of mature woody plants).

The removal of grazing from public land and uncultivated leasehold land was recommended decades ago as stock were recognised to be impeding regeneration and causing ecological decline (Land Conservation Council 1987; Blakers and Macmillan 1988; Sandell et al. 2002). On private land, where most native vegetation in the Murray Mallee and Wimmera occurs, most remnants less than 10 ha in area are still highly valued in stock management as a source of fodder and shelter for stock.

In this study we report on the recovery of remnant vegetation following stock removal. We focus on the recruitment of woody perennial species of trees and shrubs, biological soil crust and soil nutrients. Recruitment, biological soil crusts and soil nutrients have been shown to be important indicators in these landscapes (Duncan et al. 2006). Previous studies of regeneration and changes in perennial species, soil compaction, and native understorey species after de-stocking in other locations in Australia and elsewhere have mostly been on small scales (Yates et al. 2000; Sandell et al. 2002; Spooner et al. 2002; Floyd et al. 2003). Increases in perennial vegetation cover and regeneration have been observed in a number of studies; however the capacity of soils to recover is not well known. Decreases in compaction have been demonstrated (Yates et al. 2000); however the time frame of nutrient decline is poorly understood (Bolland and Allen 2003; McIntyre and Lavorel 2007).

Recovery rates of biological soil crusts from south-eastern Australia have received little attention. In arid and semi-arid environments, the open spaces between vascular plants provide a niche for a variety of lichens, bryophytes (mosses and liverworts), cyanobacteria, algae, fungi and bacteria, which have an intimate association with the top few millimetres of soil. Collectively known as the biological soil crust, these organisms play an important role in ecosystem processes. Key functions of the soil crust include: stabilising soils against water and wind erosion, regulating water infiltration, production of nitrogen and organic carbon, and influencing survival and germination of vascular plants.

A previous study in the Wimmera region of north-western Victoria (Read 2006) found that crust cover is greatly reduced or absent at disturbed sites such as small patches exposed to stock grazing and at the edge of remnant patches. In contrast, crusts can reach up to 60% ground cover in the centre of large remnant patches where disturbance is limited. In general, mosses are the group of visible crust organisms most resistant to disturbance or first to recolonise disturbed ground. Mosses were often detected at small sites, and at the edge of remnant patches when lichens were absent (Read 2006).

This study aimed to determine the recovery potential of native vegetation remnants following the exclusion of domestic stock. Our hypotheses were as follows:

1. that the probability of regeneration would increase with time since stock grazing;
2. that cover of biological soil crusts, and of perennial vegetation, would increase with time since stock grazing;
3. that annual grass and bare ground cover would decrease with time since last stock grazing;
4. that soil nutrient levels would decrease with time since last stock grazing.

METHODS

Field Survey

Site selection

In October and November 2006 we conducted biophysical surveys of 20 remnants that had stock exclusion over a known time period (between 1 and 50 years). Ideally the response of degraded native vegetation remnants to grazing exclusion would be investigated through appropriate monitoring data collected over many years at numerous sample sites. As data are generally lacking we searched for remnants where we could reliably establish the year in which stock were last able to graze. This method substitutes space for time by sampling many sites over a short period of time, to infer patterns of successional change (Foster and Tilman 2000).

Within selected Ecological Vegetation Classes (EVC, Woodgate et al. 1994) in the Murray Mallee and Wimmera Bioregions, we searched for small sites (<10 ha) by perusing GIS, through the assistance of a network of local contacts, and by consulting the Catchment Management Activity System (CAMS). The EVCs targeted were Plains Woodland, Plains Savannah, Ridged Plains Mallee and Woorinen Mallee (see White et al. 2003). Recently de-stocked and fenced sites were relatively easy to find, however we also identified small sites de-stocked for up to 50 years. Eventually we identified 20 remnants less than 30 ha in area, 19 of which were on private land (Fig. 1).

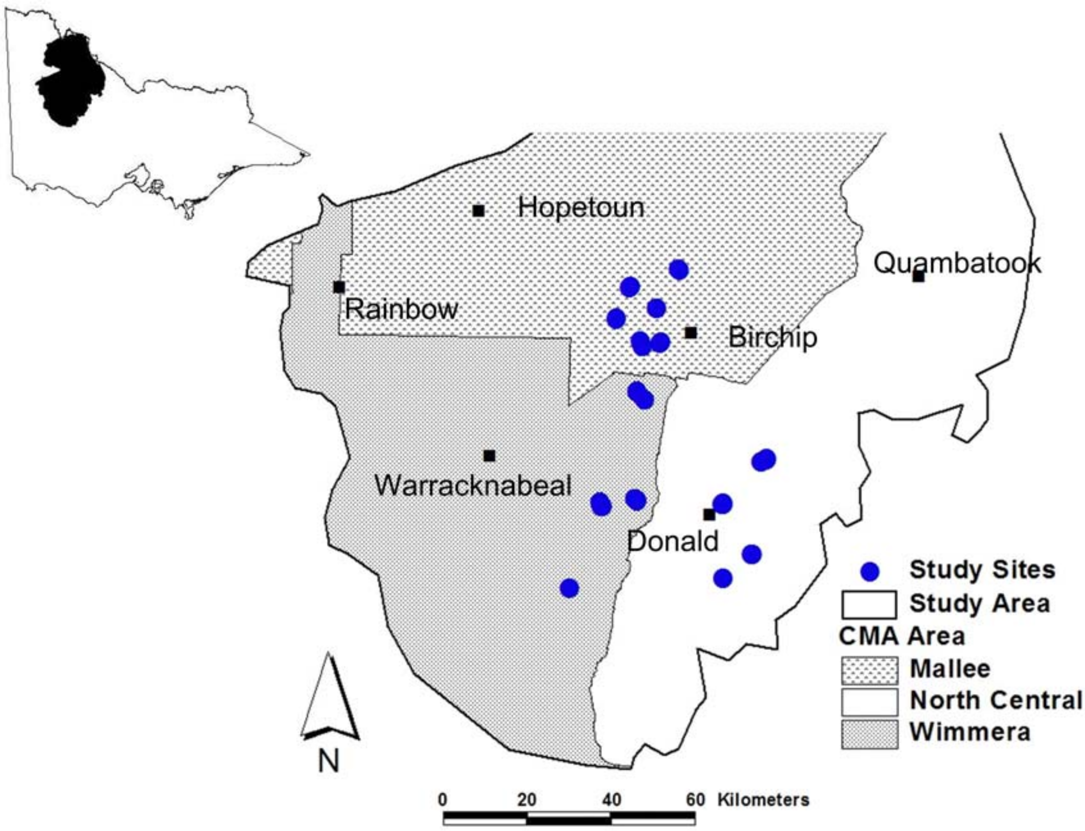

Figure 1. Location of study area and sites in northwestern Victoria

One problem commonly faced when doing space for time substitution sampling in the absence of baseline data is not knowing the condition of remnants at the time when grazing was first excluded (Spooner et al. 2002). To address this problem, we asked landholders to rate the starting condition of the remnant according to a series of photographs. The photographs were indicative of their vegetation community type in various states with the following characteristics; bare ground (low, medium, high); litter and logs (low, medium, high); and native grass cover (low, medium, high). Respondents were asked to state which picture most closely resembled the remnant at the time stock was removed, particularly the cover of bare ground, litter and logs and native grasses, and to give an overall assessment of grazing intensity at the time stock were excluded. We assigned these combinations to three levels of grazing intensity.

Light	No or little evidence of grazing, low bare ground cover; understorey vegetation (eg. grasses, small shrubs) and litter present.
Moderate	Signs of patch grazing, some bare ground, some grass tussock structure still evident, vegetation biomass moderate
Heavy	Understorey vegetation biomass low and even, high bare ground cover and low litter cover.

Table 1 Landholder assessments of remnant condition (grazing pressure) at the time stock were removed based on a series of indicative photos. The numbers of remnants in each overall category are in brackets in the first row. Mean scores based on bare ground, litter and logs, and native grass cover (high, medium, low) are presented.

Overall assessment of remnant when stock removed				Light (n=5)	Moderate (n=7)	Heavy (n=6)
Average score for each layer	H	M	L			
Bare ground cover	1	2	3	3	2.1	1
Litter and logs	3	2	1	2.6	1.3	1.3
Native grass cover	3	2	1	2.8	1.6	1

At the time these 20 sites were fenced the scores were fairly evenly spread across grazing intensities assessed by the landholder (Table 1), and spanned the full range of site scores available (1+1+1=3 – 3+3+3=9). There was no relationship between time since grazing and starting condition scores of individual sites (Statistical test of difference from correlation of 0, P=0.11, n=20). Therefore, although starting condition of the remnants was not uniform, as might be ideal for such a survey, there was no systematic bias in relation to time since grazing, which is our primary interest in this study.

Vegetation quadrats

A total of 42 vegetation quadrats were surveyed across 20 sites throughout the region, typically 2 per remnant. Two vegetation quadrats (20 m^2) were placed haphazardly near the interior of the remnant. Within each quadrat plant species were identified and cover values assessed according to a modified Domin[1] scale (~10% intervals). The presence of juveniles or saplings of native woody species, and percentage cover of broad plant groups (trees, tall shrubs, medium shrubs, small shrubs, perennial herbs, perennial grasses, exotic annuals) and soil cover (litter, bare ground, lichen/moss, soil crusts, logs - diameter >5cm length >1m, logs - diameter >10cm length >1m and rocks) was estimated. Plant origin was determined from the census of vascular plants of Victorian (Ross and Walsh 2003).

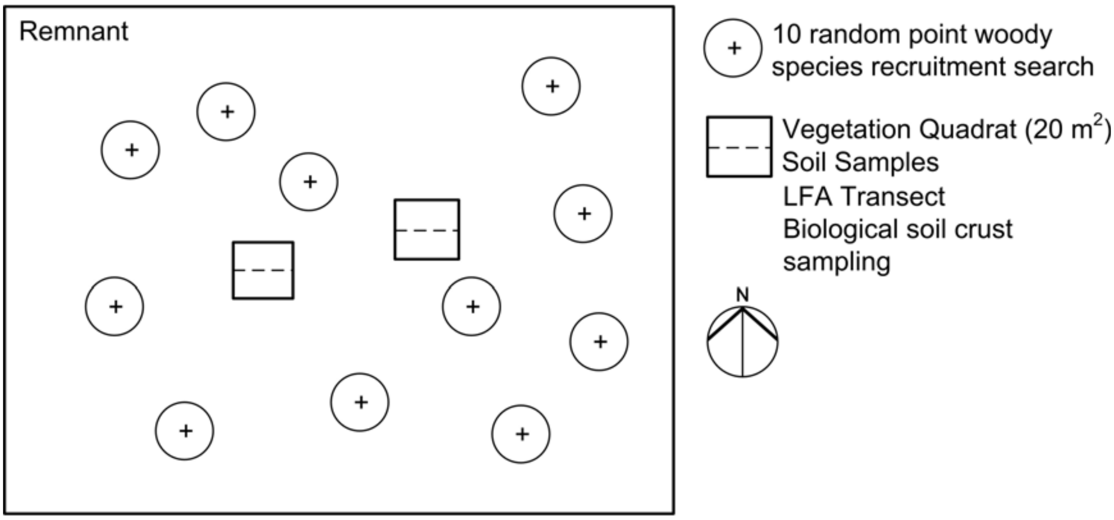

Figure 2. Representative location of vegetation, soil, and recruitment sampling within remnants.

Woody Plant Regeneration

We searched for woody species recruits within a search zone of 10 m radius from 10 random points in each remnant (Fig. 2). Random survey points were generated using the random points generator tool in ArcView (version 3.2), excluding a 20 m buffer from the edge of each remnant. Within each search zone, all adult woody species (i.e. shrubs and trees) were identified, recorded and the presence of juveniles (1cm stem diameter, <50cm tall), and saplings (1-10cm stem diameter, any height) recorded. Percentage cover of bare ground, moss/soil crusts, and tree canopy were estimated within 10 m of each point.

We recorded volumetric soil moisture (%) and soil compaction at each point using a Theta probe type ML2x (Delta-T Devices). At the same location soil compaction was recorded using a dial penetrometer. We recorded maximum force (psi) required to penetrate the soil to six depth intervals, or until 800 psi resistance was achieved.

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[1] Original technique described in Dahl, E. and E. Hadac (1941). Strandgesellschaften der Insel Ostøy im Oslofjord. Nytt. Mag. Naturvidensk., Oslo **82**: 251-312. We used one value for very low cover and few individuals "+", and even ten percent intervals from 1 – 100%.

Soil Sampling

At each vegetation quadrat location, five random soil samples were collected from between 0 cm and 10 cm depth after removal of surface litter, and pooled. The soil samples were then sent to CSBP Laboratories, Western Australia for nutrient analysis. Analyses undertaken are listed below. We present the full list of nutrient analyses for completeness and reference only. This report focuses on the available and total phosphorus data, as phosphorus enrichment was shown to be an important process in these landscapes in the previous study (Duncan et al. 2006; Duncan et al. in press).

Available P and K were extracted using the Colwell method (Colwell 1965) and their relative concentrations estimated following the method of Rayment and Higginson (1992). Total nitrogen was determined using the LECO combustion method (Sweeney and Rexroad 1987). Organic carbon was estimated following Walkley and Black (1934). Soil pH in deionised water and after the addition of CaCl was determined following Rayment and Higginson (1992). Soil pH (CaCl) was on average 0.7 points lower than pH (H_20).

List of soil nutrient data collected for this study

Texture	Organic Carbon %
Colour	Iron mg/kg
Nitrate nitrogen mg/kg	Conductivity dS/m
Ammonium mg/kg	pH
Colwell Phosphorus mg/kg	Total Nitrogen %
Potassium mg/kg	Total Phosphorus mg/kg
Sulphur mg/kg	Chloride mg/kg

Biological soil crusts[2]

At each study site crusts were sampled across microsites considered to be crust habitat and stratified by degree of sun exposure. Sun exposure influences the abundance and composition of biological soil crusts due to different tolerances of species to desiccation and shading (Belnap et al. 2001). Microsites were defined by their location in relation to canopy trees, the dominant form of shade in Wimmera ecosystems. Crusts were not sampled under canopy trees as the heavy litter and full shade excludes them.

Microsites were sampled along two transects at each study site; with each transect intercepting a randomly selected canopy patch along a north-south axis. Three microsites were sampled along each transect. Microsites were as follows:

1. Exposed – midway between canopy patches in the interpatch
2. Exposed dripline – 1m north of canopy dripline
3. Shaded dripline – 1m south of canopy dripline

[2] This element of the survey forms part of the PhD investigation of Cassia Read at the School of Botany, The University of Melbourne.

At each sampling location, the cover of biological soil crusts was estimated within a 0.5 m^2 quadrat. Six quadrats were sampled at each site. Crusts were sprayed with water before estimating cover, so bryophyte and lichen species unfurled and became more visible. This method also minimised variation due to differences in moisture availability. Percent cover of total biological soil crust was estimated as well as percent cover of morphological groups of biological crust (see Read 2006).

Cover of substrates other than biological crusts was also recorded in each 0.5 m^2 quadrat. Substrate types recorded were: perennial vegetation (<1 m tall), exotic annuals (generally weedy annual grasses), bare ground, exotic litter and native litter. The cover of the invasive weed *Poa bulbosa* was also recorded as it appears to occupy the same niche as biological soil crusts andmay out compete soil crust species.

Landholder Interviews

We interviewed landholders regarding management of the surveyed remnant, noting the stock management history of the remnant and changes in the remnant since stock exclusion. Fourteen face-to-face interviews were undertaken with landholders for the 19 private land sites. The interviews were undertaken in February and March 2007. The questionnaire (included as Appendix 1) included questions covering clearing, cropping regime, stocking rates, regeneration and values associated with the site from the 1950s to current day. Both categorical and qualitative question structures were employed. Additional material such as GIS site maps, aerial photos from the 1950s and current day and digital photos of representative vegetation communities were provided to assist the interview subjects. Landholders were encouraged to provide any additional information they thought relevant even if it was not directly related to the question. On average, the interviews took approximately one and a half hours to complete. We used the interview results for a variety of purposes, including comment on the site selection procedure (see Table 1 above), for comparison with field survey results and to assist in interpreting results and shaping the discussion.

RESULTS

Survey of de-stocked sites

Woody plant recruitment

Over all sites we observed recruits of at least 20 woody species using our random point search method (Table 2). More species recruited to Buloke and Black Box woodlands than to mallee woodlands, where *Pittosporum angustifolium* was the only species to be found at sapling or juvenile age. Buloke (*Allocasuarina luehmannii*) was the most common species found at young stages, most likely a mixture of vegetative suckers and some seedlings. All species that were found as juveniles or saplings were present as adults at the site, if not within the random point search areas.

Table 2. Number of random survey points with recruitment (juveniles or saplings) and adult plants of perennial woody species of trees and shrubs by dominant plant community.

		Woodland community type		
Species		Black Box	Buloke	Mallee
Acacia acinacea	Juvenile / Sapling	1	2	
	Mature	0	3	
Acacia oswaldii	Juvenile / Sapling	2		
	Mature	3		
Acacia pycnantha	Juvenile / Sapling		2	
	Mature		1	
Allocasuarina leuhmannii	Juvenile / Sapling	8	40	0
	Mature	13	48	1
Alectryon oleifolius	Juvenile / Sapling	1		
	Mature	1		
Callitris gracilis subsp *murrayensis*	Juvenile / Sapling		5	
	Mature		7	
Eucalyptus behriana	Juvenile / Sapling	0		0
	Mature	11		5
Eucalyptus calycogona	Juvenile / Sapling			0
	Mature			1
Eucalyptus dumosa	Juvenile / Sapling	0		0
	Mature	9		20
Eucalyptus largiflorens	Juvenile / Sapling	10	4	

	Mature	68	14	
Eucalyptus leucoxylon	Juvenile / Sapling	0	2	0
	Mature	2	2	1
Eucalyptus microcarpa	Juvenile / Sapling		0	
	Mature		2	
Eucalyptus porosa	Juvenile / Sapling	1		
	Mature	8		
Eucalyptus socialis	Juvenile / Sapling			0
	Mature			1
Eucalyptus sp.	Juvenile / Sapling	0		
	Mature	2		
Eremophila longifolia	Juvenile / Sapling	0		
	Mature	1		
Hakea tephrosperma	Juvenile / Sapling		1	
	Mature		1	
Lycium ferocissimum	Juvenile / Sapling	5		
	Mature	9		
Muehlenbeckia florulenta	Juvenile / Sapling	6		
	Mature	5		
Pittosporum angustifolium	Juvenile / Sapling	4	2	2
	Mature	2	1	0
Senna artemisioides	Juvenile / Sapling	2		
	Mature	2		
Total sum of recruits (juvenile or sapling)		40	58	2
Total sum of adults		132	79	26
Total random points surveyed for community		172	97	28

At interview, 8 out of 19 remnants were said to have had seedlings or saplings present at the time that stock were excluded. Regeneration of trees and shrubs had been observed in 12 of 19 remnants since stock were removed, and all respondents considered that the absence of stock was the primary factor in regeneration success, but also noted that regeneration followed high rainfall years.

Considering the recruitment of all woody species together, juveniles and saplings were more common in Buloke woodlands and responded more strongly to grazing exclusion than was the case in Black Box or mallee woodlands (Fig. 3). These data show that on average, in Buloke sites where stock grazing has been excluded for 15-20 years or more, recruitment of woody species occurs within 10 m of 90% of randomly selected points. In Black Box woodlands our data indicate that woody species recruitment continues to increase with time and after 30 years was present in around 50% of random point searches. By contrast regeneration in the mallee is far sparser. Even after 30 years, fewer than 10% of random searches in mallee sites yielded a sapling or juvenile of a woody species. These differences relate at least in part to the ecology of the dominant tree species in these communities, as is explored further below.

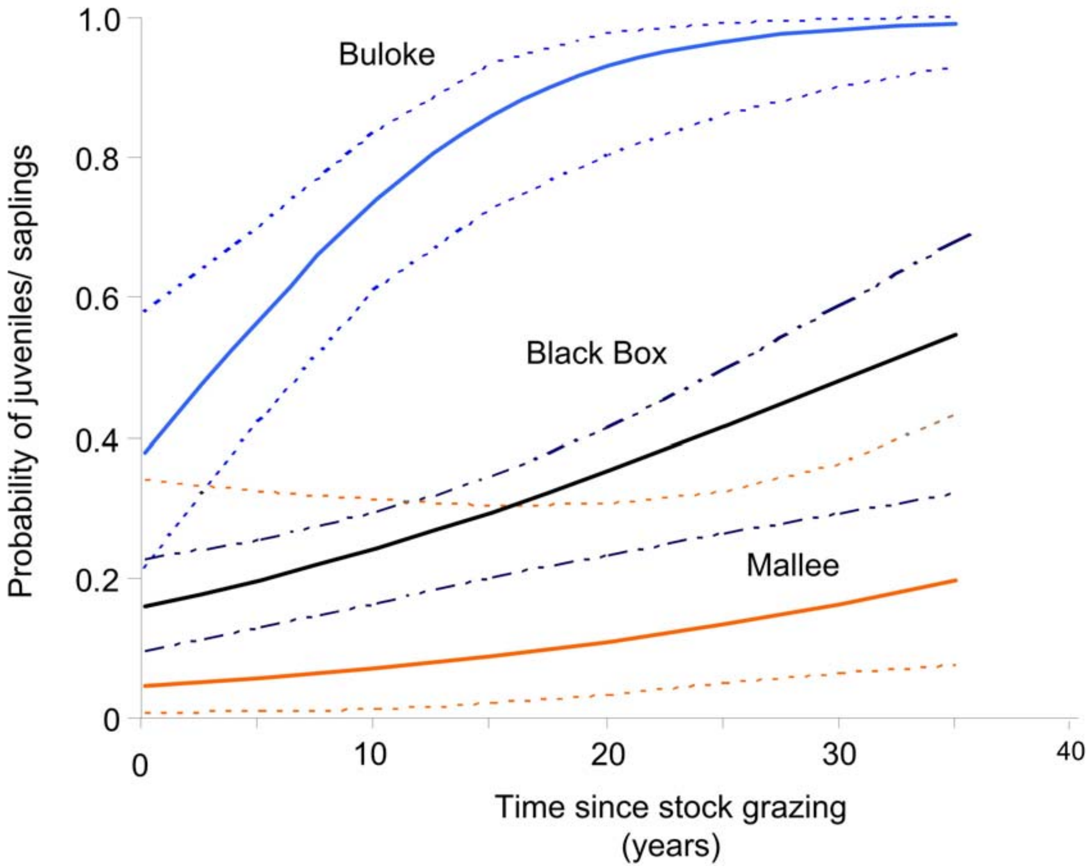

Figure 3. Adjusted probability of occurrence of regeneration (trees or woody shrubs) in Buloke, Black Box and Mallee communities with time since stock grazing (dotted lines show 95% confidence intervals around the predicted mean).

Recruitment of Buloke (*Allocasuarina luehmannii*)

Although regeneration of woody species within Buloke woodlands occurs relatively quickly in response to stock exclusion, there appears to be evidence of a lag in the appearance of Buloke (*Allocasuarina leuhmannii*) juveniles and saplings (Fig. 4). Our results indicate that the likelihood of finding regeneration from seed or sucker is very low until 15 years, but then increases rapidly with further stock exclusion to very high levels. Note that the results below (Fig. 4) are based on the probability of finding a recruit within an *individual* random search location in a remnant, which will naturally be lower than the probability of there being regeneration *somewhere* within the remnant. Beyond 15 years of stock exclusion, there is high density of Buloke recruitment. The likelihood that there will be a juvenile or sapling of Buloke within 10 m of any randomly selected point in a Buloke woodland is around 90% after 30 years of stock exclusion.

Figure 4. Adjusted probability of finding natural regeneration (from seed or suckers) of Buloke with time since stock grazing. Dotted lines indicate 95% confidence intervals around the mean.

The likelihood of finding regeneration of Buloke is significantly enhanced by the presence of an adult of the species within the same 20 m diameter search zone (Fig. 5). However, tree canopy cover itself is negatively correlated to the likelihood of finding recruits, and they are unlikely to be found when canopy cover exceeds 30% (Fig. 6a). Our results also indicate that recruitment of Buloke was strongly negatively associated with bare ground cover (Fig. 6b), and juveniles or saplings were unlikely to be found where bare ground (bare earth, as distinct from open ground with a cover of litter or biological crust) exceeded 30% cover.

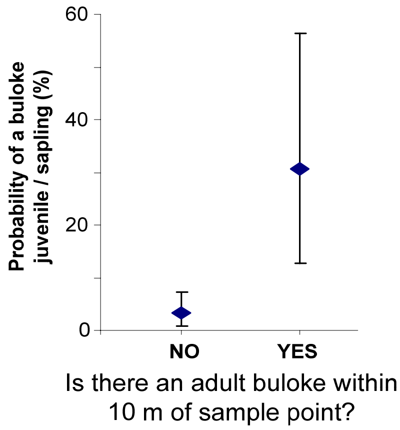

Figure 5. The likelihood of finding a juvenile or sapling of Buloke is higher where an adult is within 10 m. Error bars indicate 95% confidence intervals. Note that the adult is not necessarily within 10 m of the juvenile/sapling, but within the same 20 m diameter.

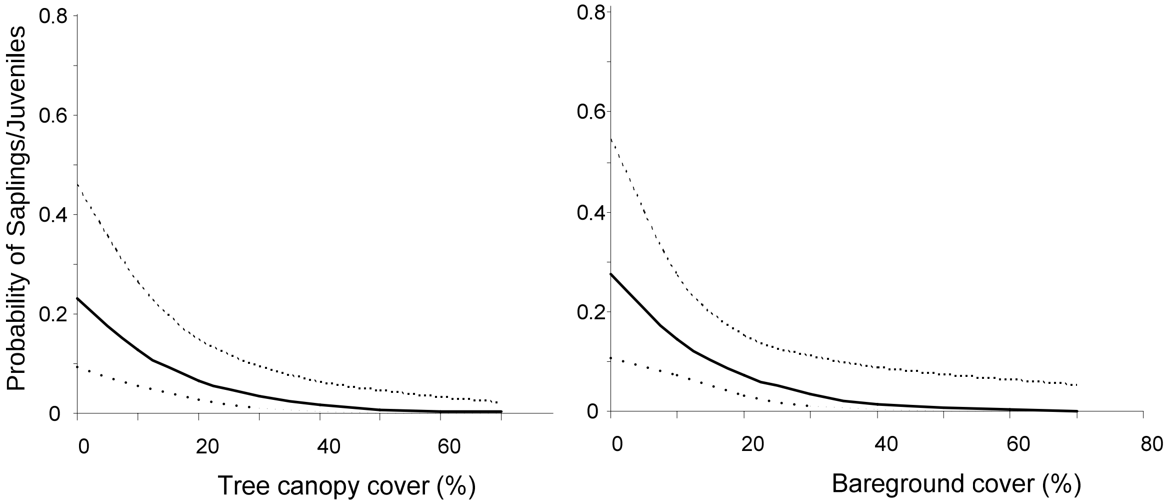

Figure 6. The occurrence of Buloke regeneration is associated with sites that have lower canopy cover (a), and low cover of bare ground (b). Dotted lines indicate 95% confidence intervals around the adjusted mean. The data in this graph are a modeled prediction given time since stock grazing of 15 years.

Biological soil crusts – mosses, lichens and liverworts[3]

There was a sharp increase in the cover of biological soil crusts with time since grazing (Figure 7). Cover values similar to those in public parks where stock have been excluded since around 1950 are reached after approximately 15 years. Mean cover of biological crusts in sites grazed more than 15 years ago is close to 60% (standard deviation ~30%). An asymptotic relationship is suggested by these data whereby no further increase in cover of biological crust occurs beyond around 15 years. This pattern requires further investigation and analysis of historical information about stocking rates prior to the most likely exclusion date for each site.

[3] These data form part of the PhD research of Cassia Read at the School of Botany, University of Melbourne

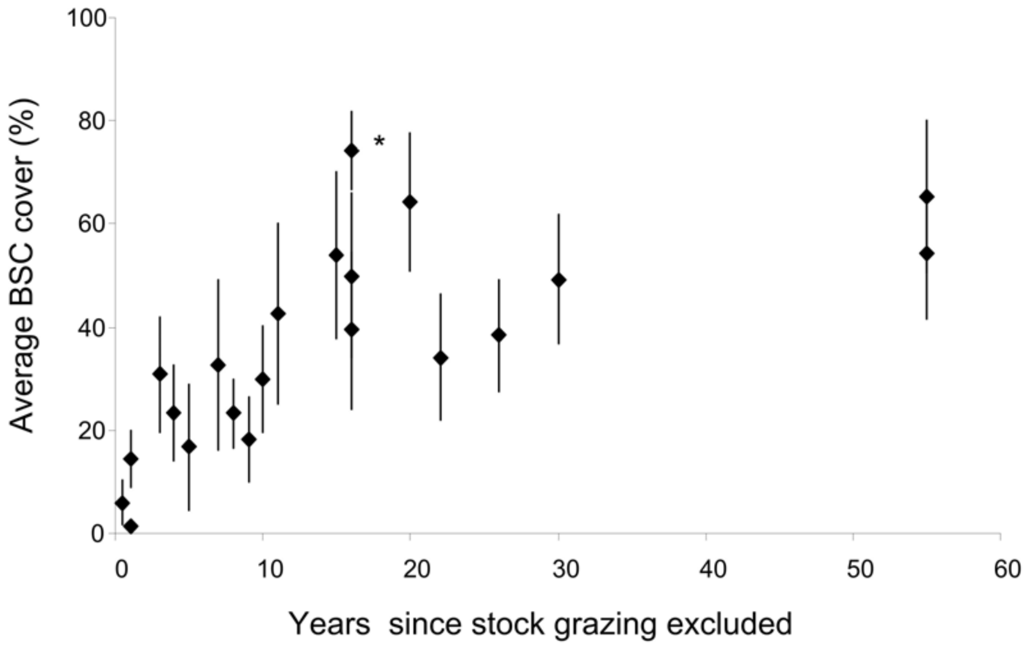

Figure 7. Mean cover of biological soil crusts (BSC) at sites with time since stock grazing exclusion. Vertical bars indicate standard error. *There is uncertainty about the date of grazing exclusion at this site. The site could have been de-stocked, or only very lightly stocked, for a longer period.

The increase in biological soil crust that followed stock exclusion is one of the more striking responses that we observed in this study. Crust cover in sites less than 5 years after stock removal was around 10%, but amongst sites of 5 – 15 years stock exclusion crust cover was over 30% (see Fig.8). Whereas biological soil crust cover increased with time since grazing there was a corresponding decline in the cover of bare ground, annual grasses and exotic litter (Fig. 9). Some other structural and ground cover layers varied relatively modestly, such as perennial vegetation and native litter cover. The patterns in bare ground, biological soil crusts and exotic cover emerged more clearly when measured within 0.5 m^2 quadrats for the cryptogam sampling than was evident from larger quadrats that we employed for the survey of vascular vegetation (20 m^2).

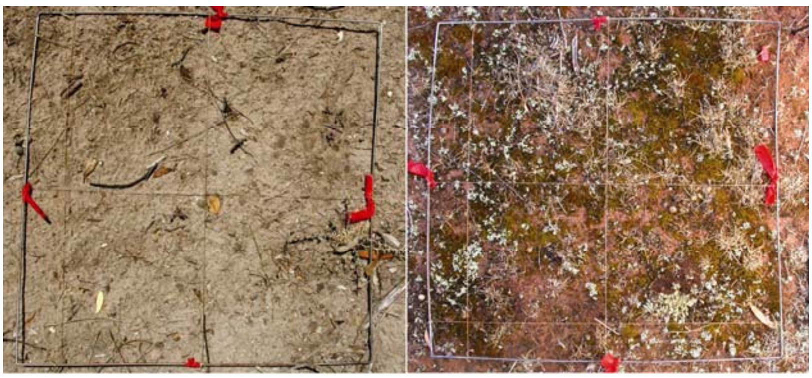

Figure 8. Example photos of low (left) and high (right) biological crust cover. Photo: Cassia Read.

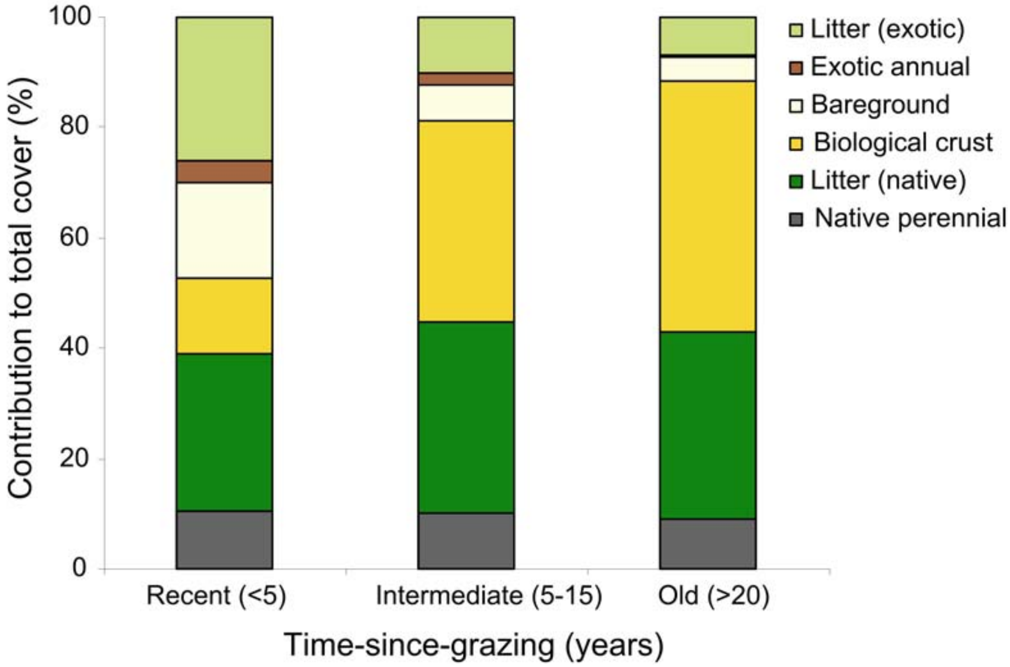

Figure 9. Change in average cover of litter, biological crust and low vegetation.

Even if overall cover of biological soil crust organisms do not increase greatly beyond approximately 15 years, our data suggest that the diversity of major morphological groups continued to increase as the time without stock grazing increased beyond 20 years (Fig. 10). The short and tall turf mosses that dominate sites within the first five years post-grazing increase in cover and continued to dominate in older sites. However, the cover and diversity of lichen groups, as well as algae and liverworts was greater in sites that had been without stock grazing for longer, in particular, those with more than 20 years rest.

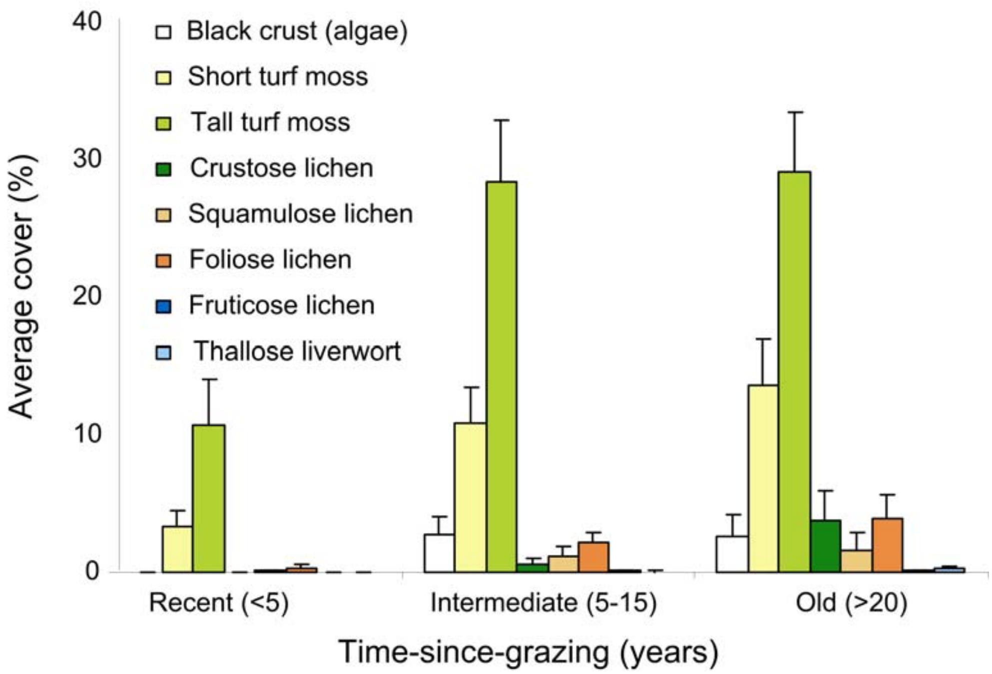

Figure 10. Change in major morphological groups of biological crust organisms comparing recently de-stocked sites against sites with longer exclusion periods.

Soil nutrient levels - phosphorus

The time since stock was excluded from remnants was not a strong driver of soil phosphorus levels in our data. Contrary to expectation, neither total P, nor available P, declined with increasing time since grazing. Soil P varied with soil type, with sandier soils having generally lower levels of soil P than heavier clay soils. Interestingly, there was evidence that the condition of the remnant *at the time that stock was excluded* was strongly related to available soil P levels (Fig. 11, P=0.008, log available P ~ startscore + time since grazing + vegetation community, model $r^2 = 0.41$).

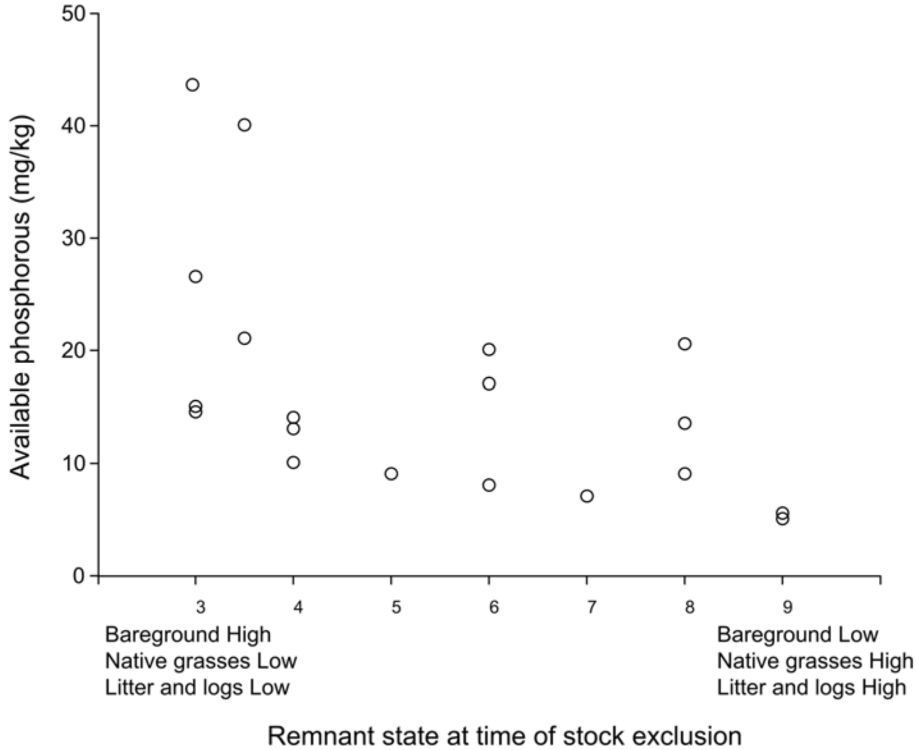

Figure 11. Site mean available P in remnant soils graphed against landholders' assessment of the condition of the remnant at the time stock were removed (from interview).

The pattern of simple assessments appearing to be important in contemporary soil nutrient assessments is supported by boxplots of raw data (Fig. 12a&b). Total P was apparently lower in sites rated lightly grazed at the time that stock was excluded than in moderately or heavily grazed remnants. The median value for available soil P from sites that were lightly grazed prior to stock removal (ca 9 mg/kg available P) was lower than 75% of all values from sites that were rated moderately or heavily grazed by the landholders. However, there was considerable overlap in distribution between sites rated moderately or heavily grazed at the time of stock exclusion. More sophisticated modelling and analysis of quoted stocking rates (number of head per ha, rotation etc) from interviews may help to clarify the situation.

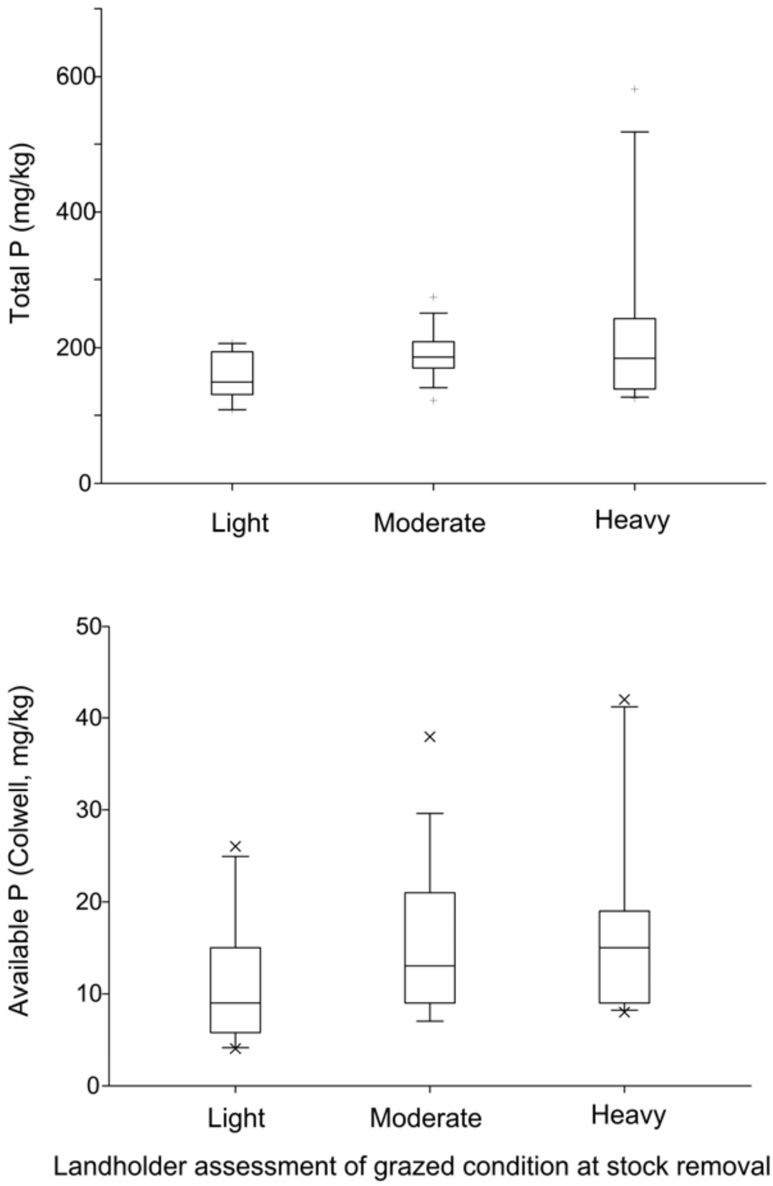

Figure 12. Boxplots of total P (a) and available P (b) for remnants assessed by the property owner to have been in a lightly, moderately, or heavily grazed state at the time stock were excluded.

These patterns require further investigation, particularly the efficacy of using landholders' recollections of the condition of native vegetation up to 30 years ago. For the time being, it is an intriguing possibility that a simple assessment of land use decades ago is more powerful than differences in time without stock grazing impacts.

DISCUSSION

Regeneration of woody trees and shrubs

Our results clearly demonstrate the value of stock exclusion for regeneration of a range of woody species of trees and shrubs. Twenty-one species were found by using our random point method across all sites. Time without stock pressure, in addition to canopy gaps and open, but not necessarily bare or disturbed ground, were the major ingredients in recruitment for these remnants. Recruitment in Buloke woodlands, including of Buloke itself, responded most strongly to time since grazing alone, whereas regeneration of Black Box and mallee is known to be more episodic. Black Box probably requires the combination of above average rainfall and low grazing pressure, and many mallee eucalypts may require fire or equivalent disturbance and nutrient pulse for successful regeneration. Our data detected Black Box regeneration but in mallee woodlands no eucalypts were found as juveniles or saplings. The failure of mallee eucalypts to recruit after several decades was also noted by Onans and Parsons (1980) in a study of small remnants of the Lowan Sands in the Victorian mallee.

Our study could not distinguish between suckers (resprouting, see Fig. 13) and seedling regeneration in Buloke, though it is likely that our sampling recorded both (Murdoch 2005). Conventional wisdom is that most Buloke regeneration observed is suckering, occurring in proximity to adult trees. We found that the probability of Buloke regeneration was positively related to the occurrence of an adult plant, which is consistent to a degree with the suckering hypothesis, and we saw some examples that were definitely resprouts. However, it should not be assumed that most Buloke regeneration observed in this study was suckers. Recent data from nearby public land sites, including a mixture of genetic studies and minor root excavation, revealed that even dense groups of Buloke trees contained genetically distinguishable individuals, and therefore seedlings, as well as suckers (Murdoch 2005). Murdoch found no sucker more than 14 m from its parent plant.

Figure 13. Vegetative suckering of Buloke from roots exposed in a cut-away ditch.

Both suckers and seedlings can contribute to the viability of the species in individual remnants, although seedling recruitment is clearly desirable for population genetic viability. Within continually grazed landscapes, it is more probable that juveniles and saplings from suckers will be observed than seedlings. Suckers presumably have greater capacity to persist by virtue of access to an established root network despite new growth being browsed each year. Seedlings may become more likely as time passes without stock grazing pressure, allowing seed to accumulate.

The species that we found as juveniles and saplings in sites where stock are excluded - eucalypts, Buloke, pines and acacias - tend to be the species that most landholders want to see regenerating on their properties. They are also important elements of the woodland structure, providing habitat for fauna and other flora, and contribute fundamentally to a range of other ecological processes. Anecdotal reports and interview data collected in this study and by Duncan et al. (2006) suggest that some farmers wait to see signs of regeneration *before* reducing stock pressure or, at least, the appearance of seedlings is the trigger for localised barriers around recruits of woody species. Our data suggest that this approach could be taken proactively by introducing stock grazing barriers in the vicinity of adult trees and shrubs, or any species that the landholder wishes to favour. Monitoring would be essential. The effectiveness of this technique in facilitating passive regeneration has been demonstrated in degraded rangelands, even in the presence of ongoing sheep grazing (e.g., Tongway and Ludwig 1996). This practice could be implemented and monitored readily, and costs little, as the required materials are frequently dropped from trees following strong winds.

Recovery of biological soil crust

These results indicate that the biological soil crusts of the Wimmera and south-eastern Mallee are destroyed by stock grazing as typically applied in the study area. However, we found that beyond 15 years of stock exclusion, total cover may recover to pre-grazing levels of around 60% (Read 2006). This level of crust cover is reached in exposed microsites outside the deep shade and litter of tree canopies. Despite relatively short recovery times for total crust cover, it is likely that recovery of species diversity will take much longer. The ecological consequences of differences in morphological group and species composition for functions such as water infiltration and plant recruitment are unknown.

Mosses were the first group to establish after grazing exclusion. Cyanobacteria (“black crust”) may also be present in the soil; however it was not possible to detect them in visual surveys in the field. A previous study in the Wimmera (Read 2006), found that mosses were the only group growing at disturbed sites such as small grazed remnants and at the western edges of remnants that are exposed to the prevailing westerly winds. Mosses may be more resilient to disturbance as they have the capacity to grow-up through deposited material and are less likely to disintegrate with disturbance from hard-hoofed animals (Belnap et al. 2001). In addition, because mosses are generally faster growing than many lichen species (Eldridge 2001) and thus recovery times of mosses will be shorter.

Previous studies in Australia have found that lichens are generally restricted to loamy soils and cracking clays (Eldridge 2001) and these soil types are common in the Wimmera. Read (2006) found mosses were found to dominate biological crusts in large undisturbed sites in the Wimmera. Although crustose and foliose lichens occupy a low proportion of ground cover in the Wimmera, they may be a good indicator of recovery from grazing. They are relatively easy to survey, are non-seasonal, and as demonstrated here and elsewhere, are responsive to disturbance. Lichens were apparently absent in recently grazed sites and lichen cover shows a distinct positive trend with time since grazing exclusion. Crustose lichens may be particularly sensitive to disturbance as they create a thin and brittle cover on the ground surface that breaks up easily with trampling.

The absence of "black crust" in recently grazed sites is surprising as the current paradigm in crust ecology (shown in Fig. 14, below) suggests that cyanobacteria and algae are the first group of crust organisms to recolonise after disturbance (Belnap and Eldridge 2001). It is likely that early colonising cyanobacteria, even if present, would not be detected with the methods used in this study. Also, visible "black crusts" may represent a complex suite of algae, cyanobacteria and perhaps fungi that take many years to develop. Microscopic analysis of collections may provide answers to these questions.

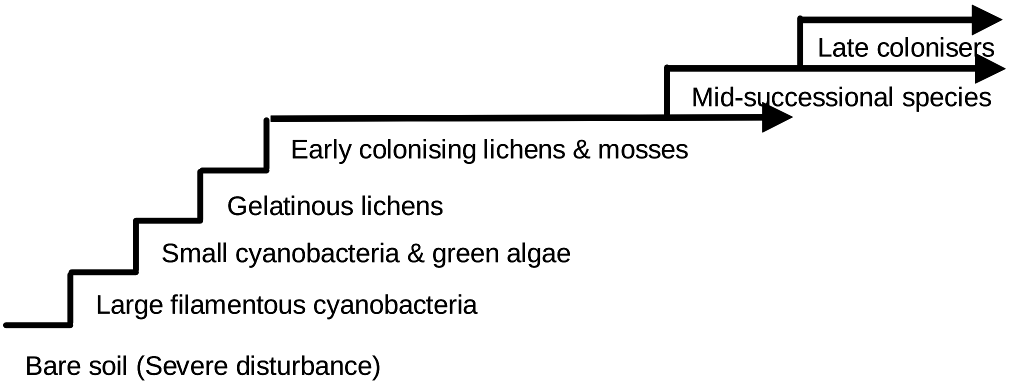

Figure 14. Succession of biological crusts following disturbance (Belnap and Lange 2001).

The close correlation between the cover of biological crusts and time since grazing exclusion, suggests that biological crusts provide a highly visible and readily interpreted indicator of recovery from disturbance, compared to other measures such as cover of native perennials and leaf litter. Despite our modest understanding of the role of crust composition in ecosystem function, a high cover of biological crusts can be interpreted as a positive indicator of ecosystem function and stability. A high crust cover will function to reduce soil loss by erosion, regardless of the composition of its flora.

Amelioration of enriched soils

The soil nutrient results were more complex but hint at an important story. Previous results showed that smaller remnants in this area were highly enriched, probably as a result of a long history of ongoing grazing rotation (Duncan et al. 2006; Duncan et al. in press). We anticipated that levels of available phosphorus would be lower in sites where stock grazing had been excluded for many years. We found no such pattern, and total soil phosphorus was independent of time since grazing. Instead, we found that available phosphorus was higher in remnants that the landholders rated as heavily grazed *at the time stock was removed*, regardless of how long ago that occurred.

Our indicator of the starting state of the remnants came from landholder interviews, where we asked them to rate the amount of bare ground, native grass and litter in the site at the time that grazing was excluded as high, medium, or low. Despite the simplicity of the measure, it must be acknowledged that in some cases people were attempting to recall how the remnant looked up to 30 years ago, some only 1 year ago. We felt that the use of photos indicative the different states was a vast improvement that helped to overcome ambiguity regarding to value judgements of heavy or lightly grazed. We have some faith in the measure, but also some questions about the quality of the remnant to which our "start score" is likely to relate. For example, it was significantly related to available phosphorus levels and this may indicate that respondents were providing some sense of the longer term grazing levels prior to the removal of grazing stock. Interestingly, a recent study from the UK (Bolland and Allen 2003) found that phosphate fertiliser application data from 1976 predicted the available P at sites 24 years later.

What is clear from these data sets, is that once a remnant is enriched, it is very difficult to remove some nutrients such as phosphorus from within a native vegetation remnant through passive means, even over the course of decades. Given that some nutrient extraction techniques, like sowing a crop or topsoil removal, are unlikely to be widely applicable within remnants on any broad scale, the next technique for investigation might be into altering the nutrient balance, perhaps by addition of other materials, in order to make the nutrients less available to plants.

The remnants we visited might be an appropriate resource to examine the supposition that soil nutrient levels are a primary barrier to the reinvasion and dominance of native perennials. High soil phosphorus levels have been convincingly linked to low diversity of native understorey species (Janssens et al. 1997; Dorrough et al. 2006), and the importance of enriched soils has been previously underlined as factor which may limit restoration possibilities (Hobbs and Huenneke 1992; Prober et al. 2002). For example, it is commonly held amongst scientists and landholders that gradually, perennial native species can reinvade and dominate formerly degraded remnants over time at the expense of annual weeds. For example a gradual shift back to a native-dominated system could follow a decline in soil nutrient levels (McIntyre and Lavorel 2007). Suppose that annuals enjoy a brief 'boom' following stock removal but eventually they draw down the soil nutrient pool sufficiently that their competitive advantage over natives becomes less telling in the competition equation. Our data do show a reduction in annual and weedy cover with time since stock grazing, but not a decline in available soil phosphorus. Two plausible options for this may be: 1) that the annuals draw down on another nutrient or element in a way which affects phosphorus availability, or 2) that the return of native dominance reflects the slow accumulation and re-establishment of native understorey species in the soil seed bank. The network of sites from the present study in conjunction with Duncan et al (2006), may provide sites and reference data on which to base a targeted study of ecological impacts of soil nutrients on native community restoration.

Recovery of ecological function and passive regeneration of degraded small remnants

The three forms of evidence we focus on in this report form a consistent story about the recovery potential of small remnants from stock grazing pressure. Whilst nutrient-enriched soils and some level of weediness may persist for decades, this does not preclude sites from re-establishing a biological soil crust cover, regeneration of woody species of trees and shrubs, and both biological soil crust and regeneration of trees and shrubs can occur over 15 years or more. Weed cover appreciably declines at most sites.

Regeneration of mallee eucalypts or woody shrub species does not easily follow stock removal. The traditional interpretation of the lack of eucalypt regeneration is the absence of fire to create regeneration opportunities. For the medium and tall shrubs, availability of seed may be a higher-order limitation as there are so few adult plants left in most remnants, and the landscape in general. Small-scale experimentation with application of fire and stock exclusion in formerly grazed remnants may provide invaluable practical information for land management agencies

Despite the promising signs of recovery detailed above, the diversity of species in a given life-form, with the possible exception of the tree layer, has been reduced by decades of continuous or rotational grazing. The typical “light” grazing regime is to stock one in every three years, which, over the course of decades would likely have exhausted the living and soil-stored presence of grazing intolerant species. In this study area, the shrub layers are particularly affected and, without direct planting into sites, would have a very low probability of recovery. Total cover of most other layers may return to “natural” or benchmark levels (*sensu* Habitat Hectares, DSE 2004) for the vegetation type with time (Fig. 15). In some cases, in the absence of any grazing pressure from other herbivores, benchmark levels may be exceeded as one structural element or species comes to occupy more space in the simplified ecological system than may have been typical in a more ‘natural’ remnant.

Figure 15. A simple fence line contrast with a 5 year ungrazed remnant on the left, with continued grazing on the other side of the fence. The ground herbs and grasses on the left hand side will be contributing to the soil seed bank each season, thus maintaining a higher level of recovery potential. However, both sides have a previous history of stock grazing and the species diversity is reduced as a result.

It is likely that, in the absence of stock grazing pressure, most remnants with a history of decades of stock grazing may reach what has been referred to as a degraded stable state(Yates et al. 2000; McIntyre and Lavorel 2007). Recovery as demonstrated in our study does not necessarily suggest viability, and many species lost will not return, or cannot be maintained unassisted. But it is a greater disappointment for landholders, many of whom expressed a desire to watch their remnant return to “pre-european” condition. Wild flowers and fauna are especially desired, but fauna and floral diversity of shrubs and herbs are the hardest ecological components to maintain in small isolated remnants that are grazed by stock. Nonetheless, stable, somewhat degraded remnants are still highly valuable for landscape ecological function. Furthermore, however small the chances of regaining sensitive ecological elements such as woodland birds and wildflower diversity, those chances will be increased by the removal or reduction in stock grazing pressure. Survival to adulthood is fraught with risks for both plants and animals, and landholders can take actions to reduce these risks. Our experience was that all landholders had observed positive changes since removing stock, although most expressed a desire for further improvement.

We finish with some recommendations that may be of assistance in the recovery of remnants, some could be effective within the context of continued grazing, all will be more effective with more time. It is difficult to draw any line between these site actions and impact on improved ecological function at the landscape or regional level. The more landholders that can be encouraged and supported to contribute by improved native vegetation management practices, the more likely are landscape level outcomes.

Our study confirms that by pursuing a policy of supporting landholders to remove stock through fencing and other programs, North Central, Mallee and Wimmera Catchment Management Authorities can contribute to their goals of increased vegetation condition and extent. There will be a limit to the amount of gain in condition achievable at site level, particularly where there has been a long history of regular or intense grazing. However, we found little evidence that the exclusion of stock has negative consequences for landholders.

RECOMMENDATIONS

1. Exclusion of stock from native remnants should be pursued wherever possible, including in sites where the ground layer appears to be highly disturbed.
   a. The current criteria for assessing applications for subsidies or funds for vegetation protection activities (size, condition, context etc) should be continued;
2. In the context of on-going grazing management within remnants, landholders should be encouraged to alter their grazing regimes in the following ways:
   a. Include a generous period without stock regularly in the remnant management cycle, particularly following good rain, and with an option to extent the rest period or a plan to protect seedlings and juveniles should they emerge:
      i. The implementation of a program for the Murray Mallee and Wimmera to support landholders excluding stock for a fixed period of time must take into account the frequency of seasons favourable for regeneration. Our data suggest that medium to long-term periods of rest from stock, say in the order of 10-30 years depending on rainfall, should be pursued.
   b. Strategically place stock grazing deterrents around individuals of remaining woody shrubs, around trees, and some examples of other species (within 2-3 m).
      i. The barrier need only be large branch (not a log) and sufficient to provide 30 – 50 cm of vertical protection.
      ii. Relatively small (a few m^2) and open barriers are less likely to be useful shelter for pest animals.
      iii. The more such barriers are placed, the more likely they are to protect an emerging seedling
      iv. Additional protection may be required where successful germination and establishment occurs; the objective is to support flowering, fruiting and seed set.

All of the above recommendations assume that landholders will continue to meet their responsibilities toward the control of noxious weeds and pest animals on their properties.

ACKNOWLEDGMENTS

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APPENDIX 1. LANDHOLDER QUESTIONNAIRE

Ecosystem Function in the Wimmera Mallee 2007 - Remnant Questionnaire

Name[4]____Date _______________

Property name/address ____

Remnant ID____

Period of time managing the remnant ____

Amount of area the landholder manages (eg. Farm size) _________________________

Before fencing/stock exclusion: Stocking Regime

Have you grazed stock in this remnant? Yes No

What year were stock excluded from the remnant? ______________________________
How long ago, can you recall what year?

What year was the remnant fenced? ____

Why were stock excluded from the remnant?
____
____
____
____

What stock type were excluded? Sheep Cattle Other__________

What was the stocking rate before exclusion? _________________________________

Eg. How many head of stock? ___________________________
Approx dse; _____________ Min__________ Max________

*PTO Stocking regime timelines

At the time of stock exclusion/ fencing could you indicate grazing pressure?
(Refer to pictures of grazing intensity)

[4] The purpose of this questionnaire is to learn about how management may affect characteristics of native vegetation in farmed lands of this region. Your name and property location will not be associated with the responses you provide for this survey; however, we would like to record it in case we need to contact you to confirm or double check a response.

Low little evidence of grazing
Moderate ground layer vegetation structure evident
High ground layer vegetation mostly evenly grazed to low level, bare ground may be exposed

Bareground	L	M	H
Litter/logs	L	M	H
Native grass	L	M	H

Natural regeneration in the past

At the time of stock exclusion were there seedlings or saplings (<1 m tall) of trees or shrubs?

Yes No Don't know/can't remember

If yes please list names/types (e.g. tree, shrub): ________________________________
____

Stocking regime since fencing

Is the remnant grazed? Yes No

What stock type is grazing? Sheep Cattle Other_________

What is the stocking rate ? ____

Eg. How many head of stock? ___________________________
Approx dse; ____________ Min_________ Max________

*PTO Stocking regime timelines

Why do you occasionally graze the remnant?
e.g. feed stock, stock shelter, remove grass / weed biomass, Other: _______________

Natural regeneration

Have there been any years where you have observed new seedlings of tree or shrubs in the remnant since it was fenced / stock excluded?

Yes No Not sure

(eg. what years/ species) ____
____
____

Did regeneration occur after: Fire event Yes No
Soil disturbance Yes No
Herbicide application Yes No

Above average rainfall Yes No
Other ___________________________________

Did they survive? Yes No

If not, what, in your opinion, is the reason?

____
____
____

Has the vegetation in the remnant changed over time? Yes No Not sure

If Yes – Describe the change____
____
____
____

Eg. increase or decrease in:

Grasses	increase	decrease	stable	unsure
Shrubs	increase	decrease	stable	unsure
Trees	increase	decrease	stable	unsure
Litter	increase	decrease	stable	unsure
Logs	increase	decrease	stable	unsure
Bare ground	increase	decrease	stable	unsure
Weeds	increase	decrease	stable	unsure

Pest Control

Have weed control activities been undertaken in the remnant? Yes No

Type of control: Chemical Grazing Slashing

Other grazing animals (eg. rabbits/kangaroos)? _________________________________

Any ripping of burrows? ____
Has any other major soil disturbance occurred? ______________________________

Fertiliser/cultivation

Has the remnant been: Cultivated/sown Yes No
Fertilised Yes No

Wood removal

Is fallen timber removed (e.g. for firewood) Yes No

If Yes – Please describe the regime (if any)
____

____

1. Selective or total clearing up

2. How often? Every 1 3 5 7 10 years

The Future

Setting aside expense, how would you like this remnant to look in 10 years?

____

____

____

For example:

the same	more trees	more animal species
gone	more shrubs	more birds
bigger	more plant species	more insects
smaller	less weeds	

Is there anything else you would like to tell me/thoughts/comments?_______

____

____