Australian Government
Land & Water Australia

Land & Water Australia

Project No: EPQ5

Final Report

Biodiversity Values and Functional Ecology of Regrowth Vegetation in Modified Landscapes

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1. Project objectives

1. Increase ecological knowledge of Queensland's mulga lands through quantitative assessments.
2. Quantify the role of regrowth vegetation in maintaining biodiversity values, soil condition, ecological function and net primary production at the property and landscape scales.
3. Establish key flora and fauna species responses to variation in native vegetation age structure and disturbance levels in semi-arid woodlands at the property and landscape scales.
4. Derive and test predictions of ecological function from surrogate indicators that can be used in property and landscape (sub-catchment) vegetation management planning.
5. Provide scientific underpinning for more effective policy and management of native vegetation in the target ecosystems and landscapes.
6. Provide practical recommendations for cost effective property planning and restoration of degraded and fragmented habitat.

2. Milestones and achievement criteria: Final Report

Milestone	Achievement criteria
1. Completion of revised outputs	Acceptance of milestone report by LWA
2. Knowledge and Adoption activities against K&A plan	Acceptance of activities by LWA

3. Introduction

At a continental scale, remnant vegetation in the Australian rangelands can be described as intact, except towards the east where intensive land clearing has occurred prior to cessation of broadscale land clearing at the end of 2006. However, ongoing clearing of native vegetation for the purposes of harvesting fodder is a legitimate management approach for large areas of south-west Queensland, and is regulated under the *Vegetation Management Act 1999*. This is particularly pertinent to mulga *Acacia aneura* woodland, a broad ecosystem type of which little is known or understood regarding its biodiversity values, particularly in modified states.

Consequently, this study was conducted within the semi-arid Mulga Lands bioregion of south-west Queensland, Australia, and specifically within two sub-regions; the Langlo sub-region and the Nebine sub-region (Fig. 1). The bioregion covers approximately 18.1 million ha, and is characterised by highly variable rainfall patterns, both in season and quantity. Average annual rainfall decreases from 500 mm in the east to less than 180 mm in the west, and the incidence of drought is frequent. Soils are generally infertile red sandy earths derived from Quaternary sediments. The primary land use in the bioregion is grazing by cattle and sheep, supporting 25% and 4% of Queensland's sheep and beef market respectively. Goats are increasingly being introduced to the region as a marketable commodity, adding to the existing and substantial herd of feral goats (Chapman, 2003).

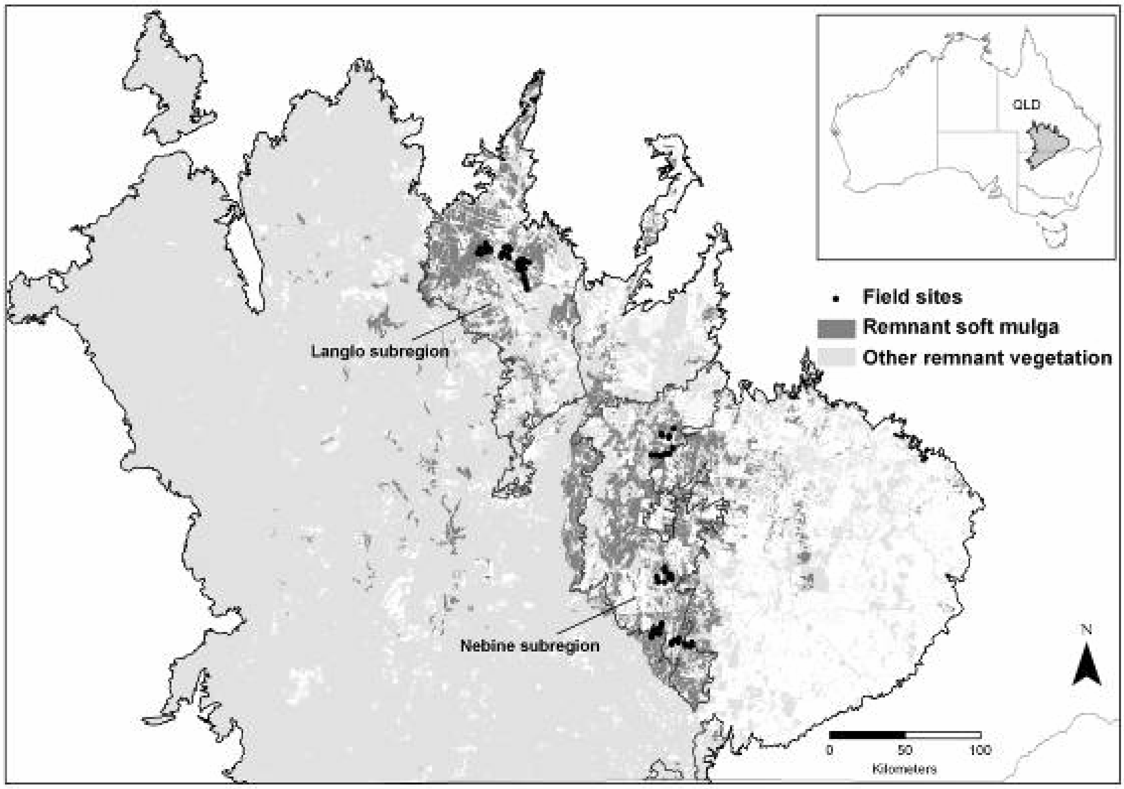

Fig. 1. Location of the Mulga Lands bioregion in Queensland, and the two sub-regions (Lango and Nebine) where sites were sampled

The Mulga Lands is a challenging region within which to conduct ecological studies, given its characteristics of;

- extreme rainfall variability, which underpins ecological responses;
- the bioregion is renowned for extensive degradation;
- there is voluminous, but disparate and poorly synthesised, literature. Biodiversity literature relevant to mulga are rare, and studies conducted at the landscape-level even more so;
- the concept of 'pristine' or pre-European "reference" vegetative state is believed to be an unrealistic ideal in the region (Page *et al.* 2009);

- Fodder harvesting techniques have been extremely variable, temporally and spatially, largely as a consequence of many iterations of policy guidelines;

- Landholders are drought and regulatory-weary, and as a result managing for or knowledge of biodiversity is often not a top priority for them;

- the landscape is largely considered as ‘intact’, but is highly modified and complicated by highly variable management;

- regrowth aplenty – seen more as a hindrance to production rather than an opportunity to “restore”.

This final report aims to provide an overview of the methods used and results obtained from the five main components of the project i) vertebrate fauna; ii) invertebrate fauna; iii) structural, compositional and functional characteristics; iv) flora; and v) landscape function and productivity. A sixth component, not originally part of the project plan, was the testing of new remote sensing products for mapping broad mulga vegetation, or condition, states. Draft manuscripts pertaining to the work conducted for this project are provided in the attached appendices.

4. Vertebrate Fauna

The vertebrate surveys conducted by this project represent the first extensive systematic biodiversity surveys in the mulga lands, particularly on private land. Past fauna survey work has typically focused on the few National parks within the bioregion (i.e. Addicott and Dollery, 1995; Dudley, 1995; Ley and Dave, 1995). Greater than 90 percent of the historical records are from incidental sightings across the region with a distinct bias towards birds and the major roads dissecting the region. This study has significantly increased the ecological knowledge base on 274 species (16 amphibian, 60 reptile, 34 mammal and 164 bird species) across the eastern mulga lands. The systematically collected data provides an important baseline which will allow future monitoring of species, in addition to the current analyses of how these fauna are responding to different mulga vegetation states.

Some of the species that the surveys increased ecological knowledge for include: 1) A rare snake, *Furina barnardi* (yellow-naped snake), a small, nocturnal species which has not previously been recorded from the mulga lands, and is the subject of a manuscript (see Appendix 1); 2) the vulnerable skink, *Egernia rugosa* (Yakka skink), a large, communal skink species at the western edge of its known range, providing an increase in the knowledge on the distribution and habitat requirements of the species; and 3) the rare small mammal, *Antechinomys laniger* (Kultarr), a nocturnal species in the critical extinction weight range, with records providing the most recent occurrence data for the eastern part of the species range since the 90’s.

4.1. Methods

For the vertebrate fauna component of the project, specifically birds and reptiles, our primary objective was to investigate how these fauna responded to different mulga vegetation states at site and landscape scales. A landscape was defined as a circular spatial extent encompassing 314 ha, centred on the sample site. We sampled five broadly different mulga vegetation states (remnant mulga and four non-remnant mulga states; low regrowth mulga < 15 years since last harvest; cleared mulga pasture; selectively cut mulga and dense regrowth mulga 15 – 30 years since last harvest; Fig. 2) within two landscape types; intact landscapes with >70% remnant vegetation retained and relictual landscapes with <30% remnant vegetation retained (Fig. 3).

We used 1:100 000 remnant and pre-clear regional ecosystem mapping (Environmental Protection Agency, 2005) to delineate remnant and pre-clearing extent of the regional ecosystems representing 'soft mulga' vegetation and 'other' vegetation. To delineate areas of non-remnant vegetation, we used the Statewide Land and Tree Study (SLATS) mapping, which uses Landsat Thematic Mapper and Enhanced Thematic Mapper Plus satellite imagery to map woody cover (Department of Natural Resources and Water, 2008). We combined this with the pre-clear regional ecosystem mapping of soft mulga and other vegetation to distinguish patches of non-remnant soft mulga vegetation and non-remnant other vegetation in the landscape. We then used the resultant remnant and non-remnant mulga vegetation mapping over our accessible properties to identify potential mulga vegetation patches within intact and fragmented landscapes for sampling. These patches were visited in the field, and based on site inspection and local land manager knowledge were categorised into one of the five vegetation states.

We selected eight sites within each of the ten mulga vegetation state by landscape treatments, to give a total of 80 sample sites. Sites were located at least 1 km from each other and 100 m from roads, fences and different vegetation states. They were also located to be fully within a paddock and at least 200 m from the nearest artificial waterpoint, regardless of whether it was inside or outside of the paddock boundary.

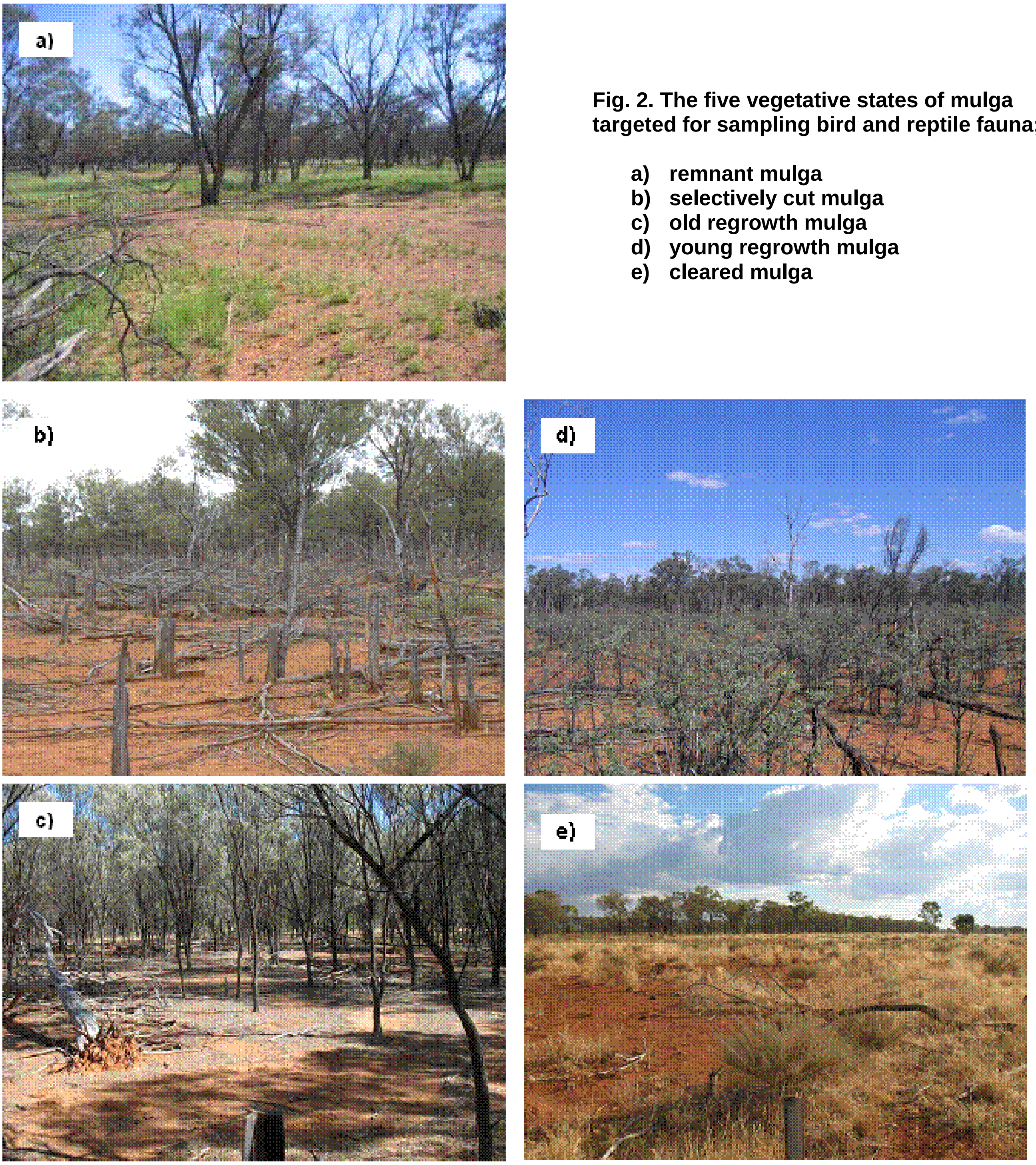

Fig. 2. The five vegetative states of mulga targeted for sampling bird and reptile fauna;

- **a) remnant mulga**
- **b) selectively cut mulga**
- **c) old regrowth mulga**
- **d) young regrowth mulga**
- **e) cleared mulga**

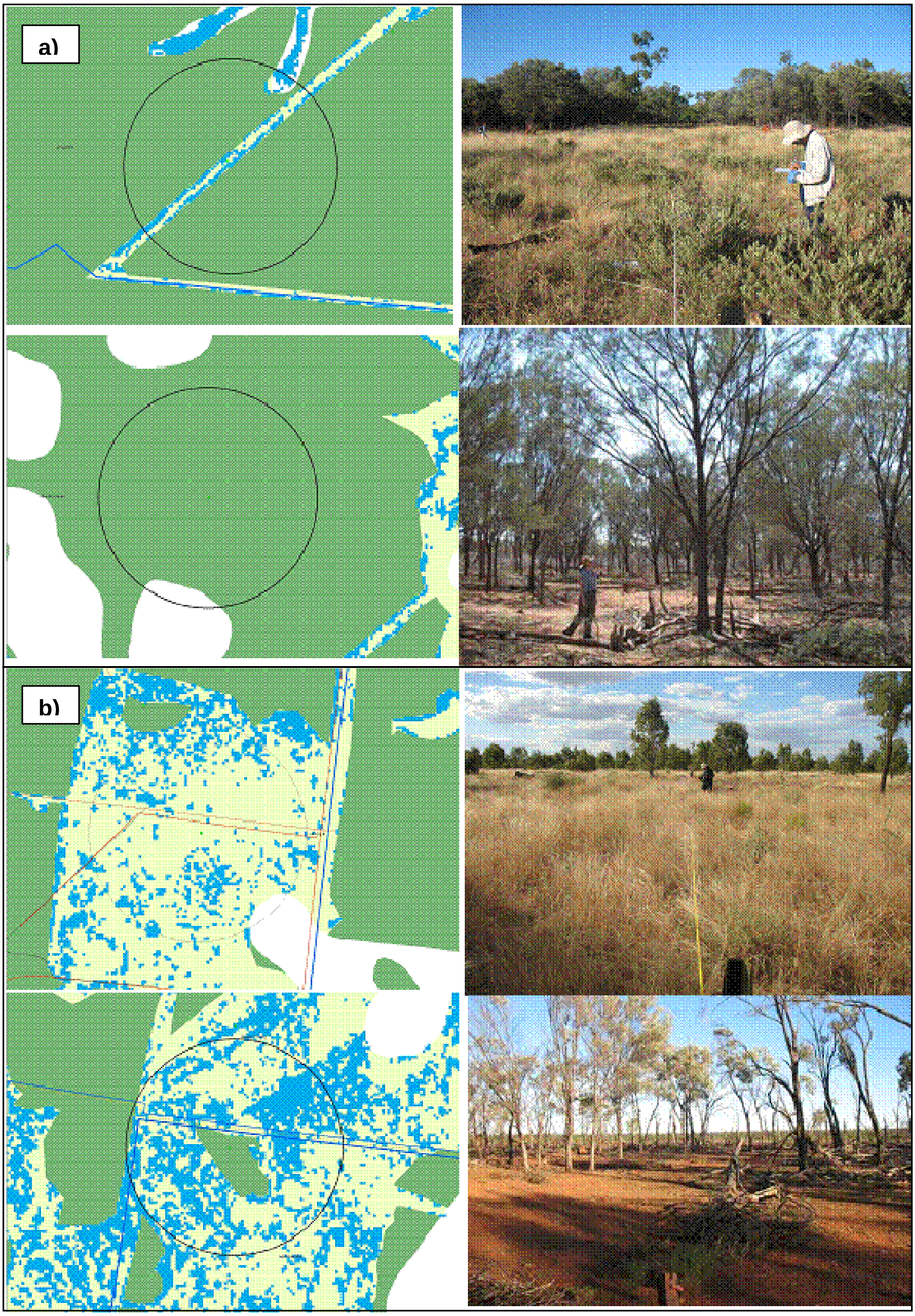

Fig. 3. Examples of the two landscape treatment types; a) intact landscapes with >70% remnant vegetation retained and b) relictual landscapes with <70% remnant vegetation retained. Green areas represent mapped remnant mulga vegetation, yellow areas represent pre-cleared mulga, and blue areas represent non-remnant mulga.

4.2. Diurnal birds

Of the 95 bird species recorded during the systematic surveys, 66 were detected at four or more sites and were thus included in the assemblage analyses. The PERMANOVA (See Appendix 2 for details regarding methods and preliminary results) revealed significant differences in bird species composition between the vegetation state treatments ($F_{4,70}$ = 4.627, P = 0.0001) and the landscape treatments ($F_{1,70}$ = 3.983, P = 0.0002), but no significant interaction (Fig. 4). Post-hoc pairwise comparisons indicated that bird assemblages were dissimilar between all vegetation states, except between remnant and selectively cut mulga, and between young regrowth and cleared mulga.

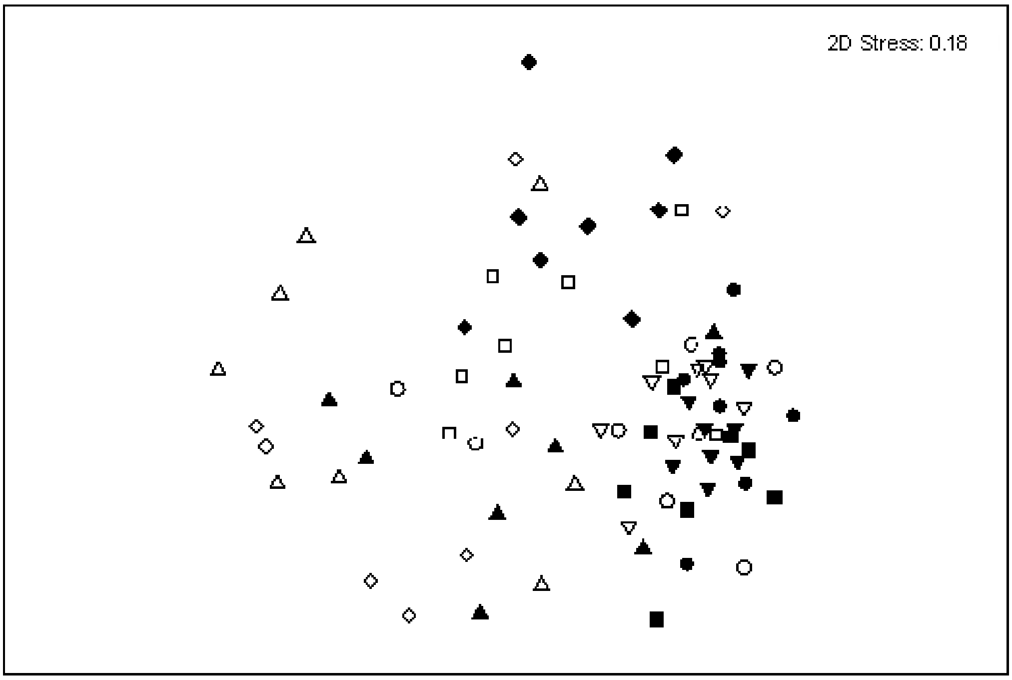

Fig. 4. Multidimensional scaling ordination of bird assemblages for the vegetation state and landscape type treatments. Symbols: Open symbols depict sites in relictual landscapes, and closed symbols depict sites in intact landscapes. Circles represent remnant sites, squares represent selectively cut sites, inverted triangles represent old regrowth sites, upright triangles represent young regrowth sites and diamonds represent cleared sites.

Diurnal bird species that were more commonly found in the large intact tracts of remnant mulga included the brown treecrepper, weebill, white-browed treecreeper, red-capped robin and yellow-rumped thornbill – all small passerine species (Plate 1). However, while weebill, red-capped robin and yellow-rumped thornbill were able to inhabit patches of non-remnant vegetation (i.e. young regrowth and cleared mulga) in the intact landscapes, the brown treecreeper and white-browed treecreeper were very much restricted to the more remnant patches of mulga vegetation (i.e. remnant, old regrowth and selectively cut mulga). Species that were more commonly detected in more variable landscapes in a mosaic of regrowth and remnant mulga included the crested bellbird and willie wagtails. Yellow-throated miners (Plate 2), pied butcherbirds and galahs appear to dominate the cleared and regrowth landscapes with relictual remnant mulga retained in the landscape. These types of patterns have been described in other fragmented landscapes (e.g. Martin *et al.* 2006; Hannah *et al.* 2007).

Plate 1: From left; Weebill and red-capped robin and white-browed treecreeper. Examples of small passerine bird species requiring large areas of remnant vegetation, and refuges from the influence of Yellow-throated miners, in the mulgalands

Plate 2: Left: Yellow-throated miners. A hyperagressive honeyeater that appears to prefer increased levels of cleared mulga in the landscape

Model averaging and hierarchical partitioning of 11 landscape-scale and site-scale explanatory variables (Table 1) revealed that the most influential variable on the abundance of small passerine birds was the abundance of yellow-throated miners (Fig. 5). This had a negative effect upon small passerines, as did the next most influential variable, shrub cover. The detrimental impact of hyperagressive noisy miners upon other small, insectivorous bird species has been well documented (Dow 1977; Grey *et al.* 1987, 1998). In the mulga lands, the cogeneric yellow-throated miner appears to be acting similarly to the noisy miner in the more easterly habitats. The interesting thing to note here is that in the literature shrub cover has been identified as an extremely important variable for small passerine birds, providing foraging and nesting opportunities (Hannah *et al.* 2007; Eyre *et al.* 2009).

Table 1: List of explanatory variables used to test potential influences on diurnal birds

Variable	Code	Description
Yellow-throated miner	ytminer	Abundance of yellow-throated miners
Regrowth in the landscape	regrowth	% of regrowth mulga within a 1-km spatial extent of a site
Cleared vegetation	cleared	% of cleared vegetation within a 1-km spatial extent
Mulga Age	regage	Approximate age of the mulga vegetation sampled
Distance to water	dwater	Distance to nearest artificial waterpoint
Shrub cover	shrubcover	% canopy cover of stems in the shrub layer (<5 cm DBH)
Small tree density	smltrden	Abundance of small trees > 5cm < 10 cm DBH
Large trees	totlarge	Abundance of large mulga trees > 30 cm and poplar box trees > 40 cm DBH
Fallen woody material	fwm	Abundance of fallen woody material >0.5m long and >10 cm DBH
Organic litter	litter	% organic litter cover
Bare ground	baregrd	% bare ground cover

However, in the mulgalands, small passerine species appear to have a negative response to increased shrub cover. This is because shrub cover in the mulgalands in predominantly made up of *Eremophila bowmanii* or *E. gilesii*, low forming shrubs (often referred to as *woody weeds*) which can form a dense layer. The increase of *Eremophila* in the mulgalands has been attributed to a combination of increased grazing pressure, reduced competition – particularly during dry times – and lack of fire (Noble 1997; Page *et al.* 2000). We suggest that the negative response between small diurnal birds and shrub cover reflects the possibility that a dense cover of *Eremophila* reduces foraging opportunities for many ground-foraging insectivore species.

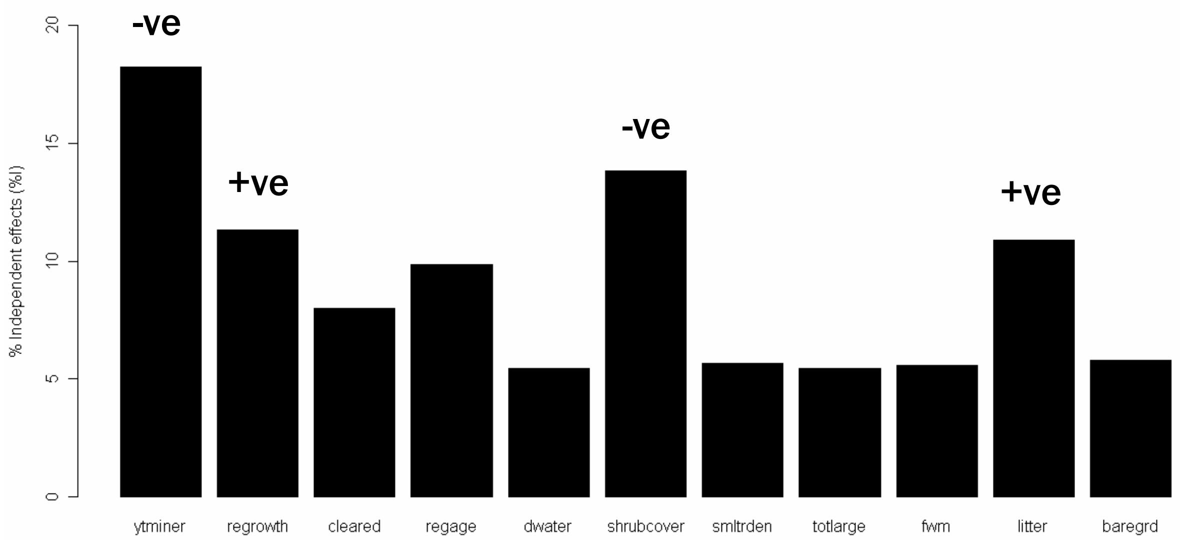

Fig. 5. Independent effects (%) of a number of landscape-scale and site-scale variables upon abundance of small passerine species (grouped), using hierarchical partitioning.

The most influential variable explaining the abundance of yellow-throated miners was the amount of landscape that was cleared (that is, no remnant and no regrowth). This was a positive response, and other variables had relatively little influence (Fig. 6.).

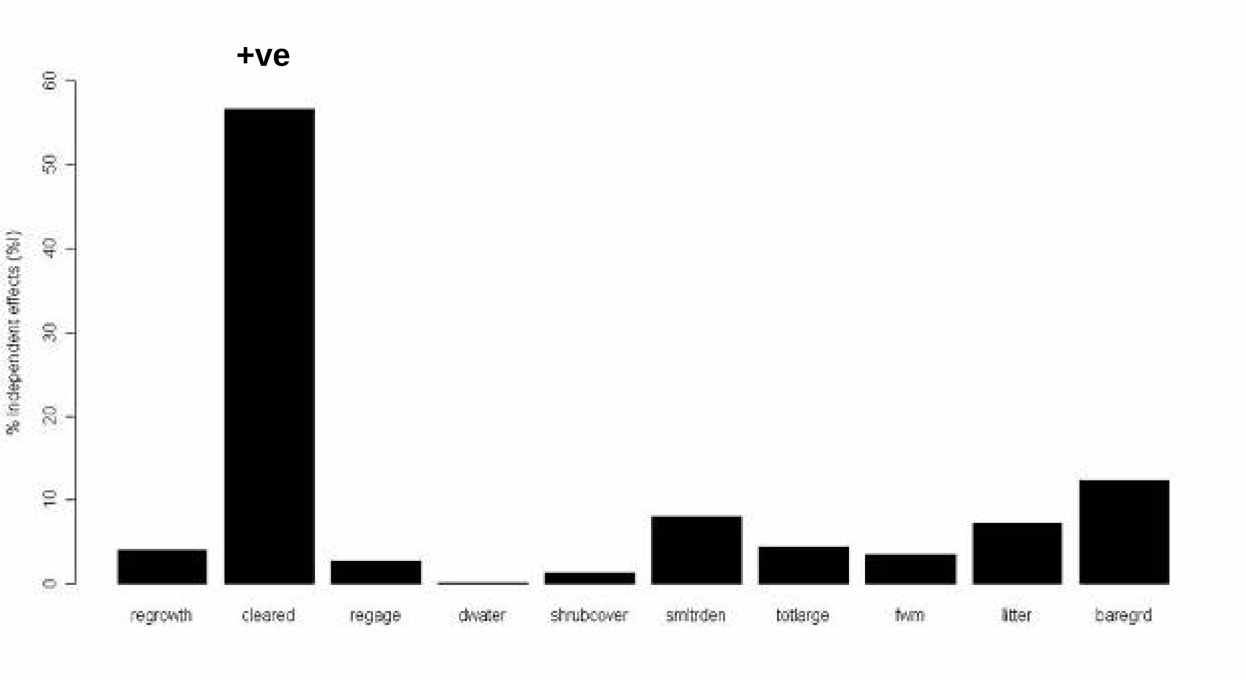

Fig. 6. Independent effects (%) of a number of landscape-scale and site-scale variables upon abundance of yellow-throated miners, using hierarchical partitioning.

4.3. Reptiles

We used multi-dimensional scaling (MDS) ordination and pairwise ANOSIM in PRIMER on the reptile data collected over two seasons at 60 (of 80) sites. MDS aims to maximise rank-order correlation between distance measures and distance in ordination space. We found that reptile species composition differed significantly between the four landscape treatments (Fig. 3; remnant mulga in relictual regrowth landscape; intact remnant landscape; regrowth or cleared mulga in an intact remnant landscape and relictual landscape), except between remnant in regrowth landscapes and intact remnant landscapes, and between regrowth in remnant landscapes and largely regrowth landscapes (Global R = 0.13, P < 0.001; Fig. 7). Therefore, reptiles appear to be responding to the site-scale level vegetative state (i.e. remnant or regrowth) rather than at the landscape-scale level. Given the relatively small home ranges of most reptiles, this result was not entirely unexpected.

A species that characterized the species assemblage of remnant mulga was the velvet gecko *Oedura marmorata* (Plate 3). This is an arboreal gecko, and not much is known on its ecology. The ground dwelling beaked gecko *Rhynchoedura ornata* tended to be more common in the regrowth mulga patches, and characterized assemblages in these landscapes.

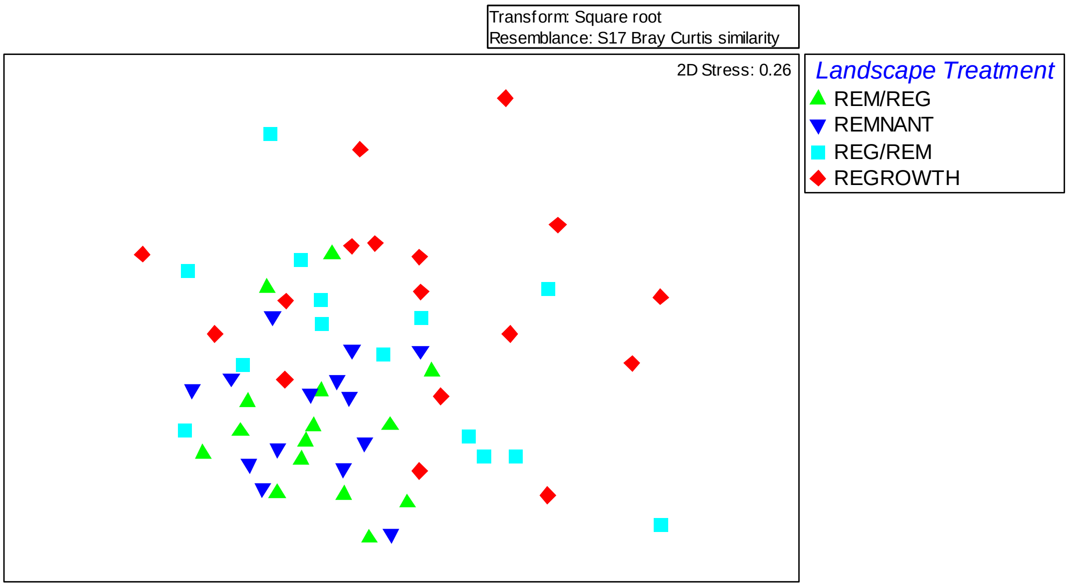

Fig. 7. Multidimensional scaling ordination of reptile assemblages for the four landscape scale treatments; remnant in regrowth landscape, predominantly remnant landscape, regrowth patch in a remnant landscape, and predominantly regrowth landscape.

Plate 3: Velvet gecko *Oedura marmorata* – an arboreal species found predominantly in landscapes of intact remnant mulga

Model averaging and hierarchical partitioning of the landscape-scale and site-scale explanatory variables described in Table 1, identified the number of large, live trees as having the most influence on the abundance of *O. marmorata* in the mulgalands (Fig. 8). Increased densities of small trees had a negative influence on this species, as did increased proportion of cleared mulga in the landscape. Thus, it appears this species is very attached to more mature, intact stands of mulga. On the other hand, *R. ornata* responded to increased levels of bare ground, and proportions of regrowth and cleared mulga at the landscape level (Fig. 9). This species had a negative relationship with the total number of large tree. These two gecko species provide a good illustration on the variation in species responses – and why using a basic indicator such as species richness is probably not so informative in the mulga.

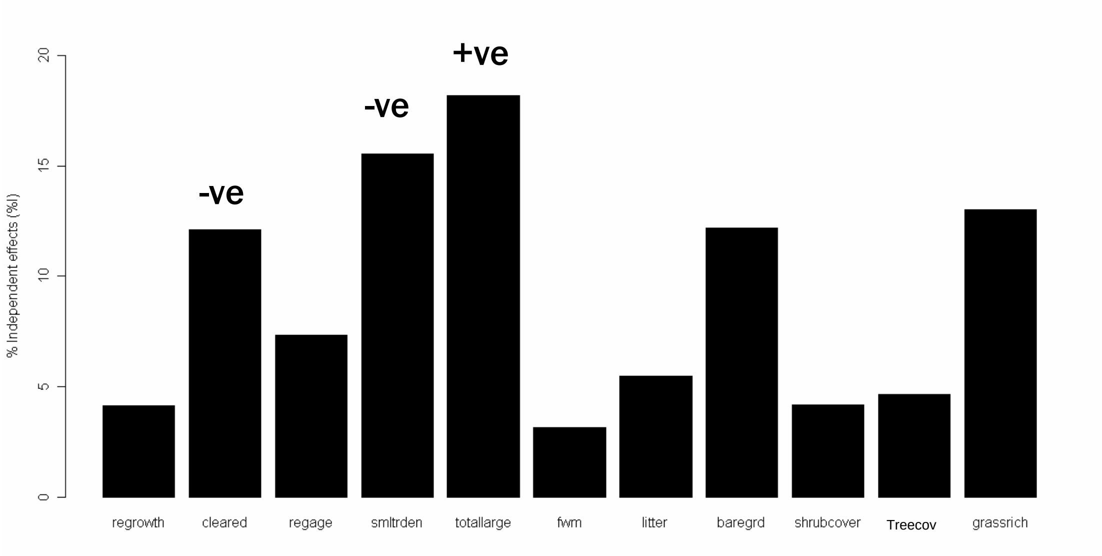

Fig. 8 Independent effects (%) of a number of landscape-scale and site-scale variables upon abundance of *Oedura marmorata*, using hierarchical partitioning.

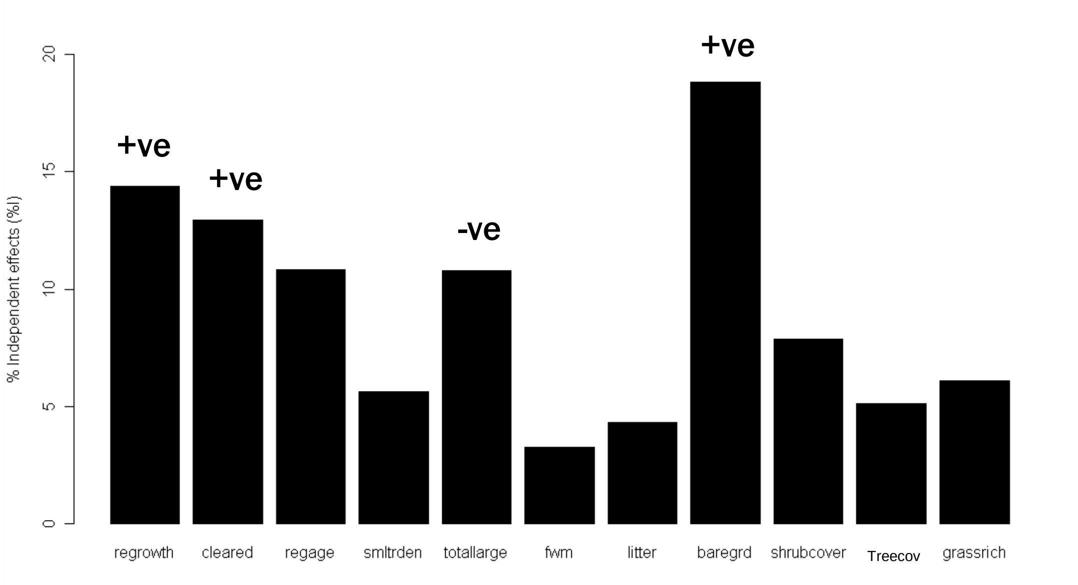

Fig. 9 Independent effects (%) of a number of landscape-scale and site-scale variables upon abundance of *Rhynchoedura ornata*, using hierarchical partitioning.

5. Invertebrate fauna

5.1. Methods

Using the experimental design proposed for vertebrate and floristic studies (cf milestone report 3) 16 sites representing five in A landscapes (regrowth in remnant), five in B landscapes (remnant in regrowth), and three each in C (regrowth) and D (remnant) were established. At A and B sites, paired plots were established to sample the patch and the matrix. At C and D sites a single plot was established. Each plot consisted of 2 lines of 5 traps separated by at least 100 m. Plots were established more than 50 m from vegetation edges. A total of 260 pitfall samples were collected using this design, with individual traps within a plot bulked for sorting. Samples were collected during winter 2007 and spring/summer 2007.

Within each plot, five 11 cm diam (9 cm deep) plastic food containers were set into the ground, left for one week to settle, and partially filled with 200 ml of 60% ethylene glycol to which was added a few drops of detergent (to break surface tension). Traps were left open for 4 days, collected and contents bulked. Traps were located within each plot to sample the range of micro-habitats available (open areas, base of trees, against logs).

5.2. Results and discussion

Invertebrates are useful barometers of ecological change, and ants are especially responsive to habitat alteration. Of the total ant species pool, 64 species were found at fewer than 5% of sites over both collecting seasons: 35.9% were found only in remnant sites, 50% found only in regrowth sites, and 14.1% were found in both remnant and regrowth. These proportions are in contrast to ants in brigalow remnants and regrowth (House *et al.* 2006) where most rare species (54%) were found only in remnant vegetation. Full results from this component of the study are provided in Appendix 3.

In these quite open mulga communities, changes in canopy cover are not necessarily matched by major changes in habitat conditions at ground level, unless post-clearing management alters the amount and distributions of key habitat features such as ground cover and fallen timber.

However, vegetation cover at landscape level (1 km) does appear to have an influence on ant species richness, albeit quite weak, with increasing richness at higher levels of remnant vegetation and decreasing richness as both the proportion of regrowth and cleared land increases (Fig. 10). The proportion of remnant vegetation at 1 km scale was the most important determinant of species richness, but landscape pattern did not alone explain the ant assemblage composition as shown by ANOSIM (Fig. 11). Habitat characteristics such as the amount of ground cover and the presence/absence of tree canopies were also important, reflecting the findings of Debuse *et al.* (2007).

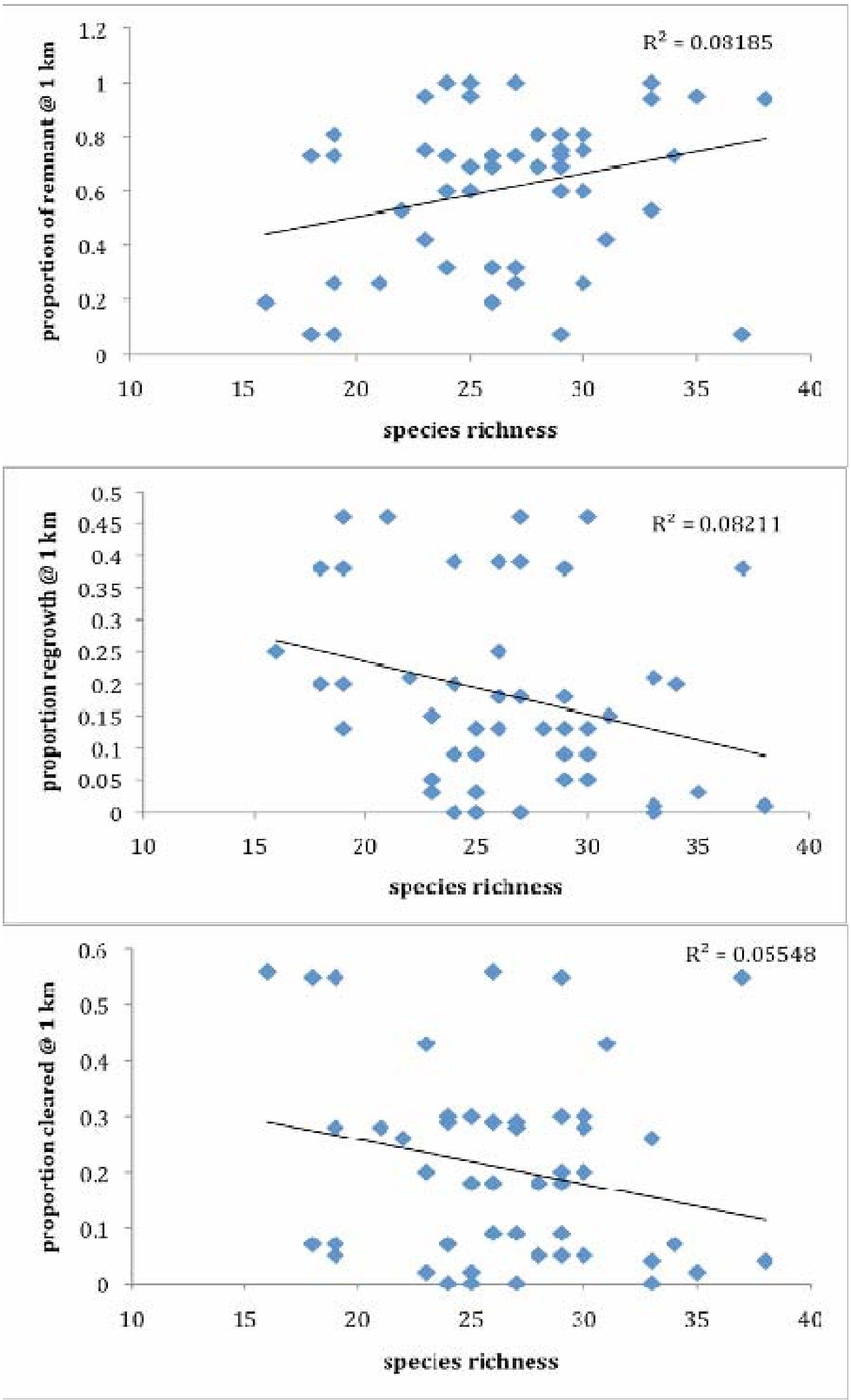

Fig. 10. Ant species richness in relation to vegetation pattern at 1 km scale.

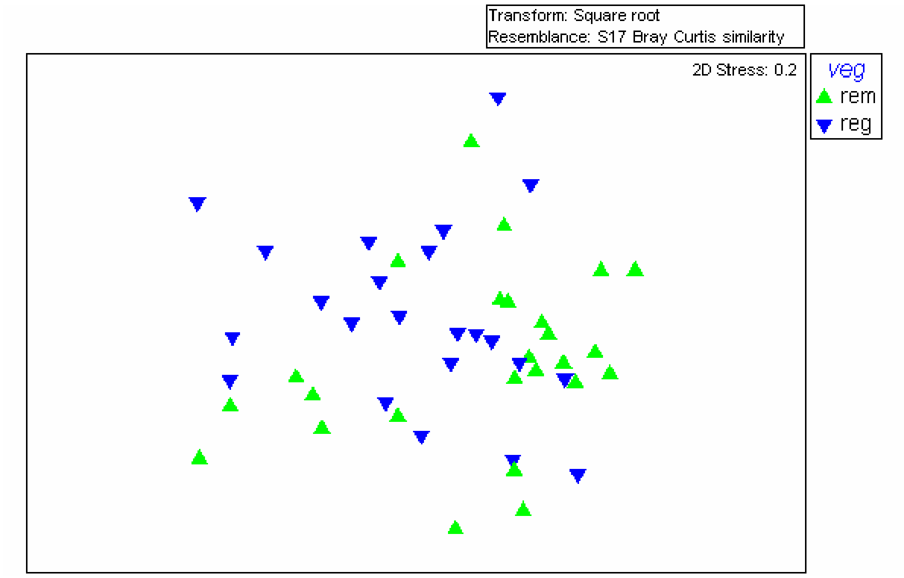

Fig. 11. NMDS of combined ant data, omitting extreme outliers.

Preliminary analyses of other invertebrate groups suggests a similar story to the ants – there is some influence of vegetation pattern on assemblage composition at Order level, but the controlling factors have not yet been determined, nor has the relative influence of landscape and habitat attributes on species richness.

From a conservation perspective, tree clearing in the Langlo subregion has not substantively reduced ant species – there is turnover between remnant and regrowth sites but no difference in species richness between them. More substantial alterations in habitat quality however, from increased "tidying up" (i.e. stick-raking) and sowing of pasture grasses, may lead to further changes in ant diversity. This is untested in this project.

6. Characteristics of mulga vegetative states

The response of 12 structural, functional and compositional variables to each of the five mulga vegetation states was examined using one-way Analysis of Variance (ANOVA). The traits selected to test were based on both functionality from a biodiversity and grazing land production perspectives. Table 2 summarises the results of the series of analyses. If the response was significant at $P < 0.05$, then the direction of the response is illustrated as increasing (arrow pointing up) or decreasing (arrow pointing down). For easier visualisation, the arrows were coloured green if the response is desirable (e.g. decreased soil erosion is a desirable response) and coloured red if undesirable (e.g. increased soil salinity is an undesirable response). Thus, Table 2 allows a quick appreciation of the structural, compositional and/or functional contribution each vegetation type contributes.

Of the 12 traits, remnant mulga had seven significant responses, and all were 'desirable'. Soil salinity, soil erosion and bare ground were all significantly reduced in remnant mulga, whereas the abundance of seed collecting areas for regeneration and herbage production, habitat trees, litter and floristic diversity were all significantly higher. Old, dense regrowth mulga and selectively cut mulga each had less significant responses compared with the other three vegetative states, with both desirable and undesirable responses. Young regrowth had six significant responses, but all were undesirable. Soil salinity and density of Eremophila shrubs and yellow-throated miners were increased, whereas litter cover and habitat trees were significantly less. Cleared mulga had similar responses, except that forage biomass for grazing land production was increased, and florisitic diversity was also high.

Table 2: Direction of responses of 12 structural, functional and compositional variables to each of the five mulga vegetation states.

	Remnant	Old regrowth	Selective cut	Young regrowth	Cleared
Soil salinity	↓			↑	↑
Soil erosion	↓				↑
Fertility & seed collecting	↑				↓
Forage biomass		↓			↑
Shrub density		↓		↑	↑
Habitat trees	↑			↓	
CWD					
Litter cover	↑		↓	↓	↓
Bare ground	↓			↑	
Anti-keystone		↓		↑	↑
Small passerines		↑	↑		↓
Floristic diversity (after rain)	↑	↓			↑

Note: Habitat trees = large, hollow-bearing trees; CWD = Downed coarse woody debris; Anti-keystone species = Yellow-throated miner; Small passerines = all birds < 25 cm head-tail length.

7. Floristics

7.1. Methods

Floristics data was collected from 58 sites sampling remnant and regrowth mulga in the two sub-regions (Fig. 1). A ‘site’ was made up of four separate subplots, oriented 50 m apart to sample across the remnant to regrowth gradient. At each subplot, a transect was located to sample remnant mulga (Ta), remnant edge (Tb), regrowth edge (Tc) and regrowth mulga (Td). Each transect was 62 m long by 2 m wide and parallel to each other as well as to the remnant-regrowth boundary edge. Ta was located 100 m and Tb was located 10 m into the remnant from the boundary, Tc was located 10 m from the boundary within the regrowth and Td 100 m into the regrowth (Fig. 12).

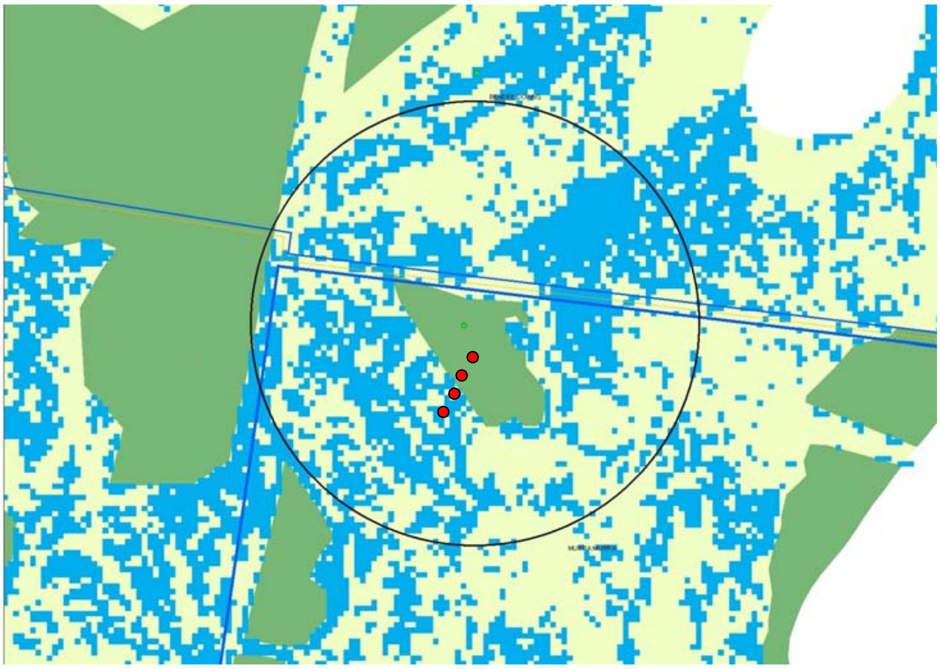

Fig. 12: Floristic sampling across remnant and regrowth mulga vegetation. The red dots represent each of the four subplots (dark green = remnant soft mulga; pale green = pre-cleared soft mulga; blue stippling = regrowth soft mulga)

7.2. Vascular plants

Vascular plant species found in each transect were recorded. The 62 m long transect was further divided into 2 m, 4 m, 8 m, 16 m, 32 m, to give sampling areas of 4 m^2, 8 m^2, 16 m^2, 32 m^2 and 64 m^2 respectively. This method provides an ‘importance score’ based on the premise that species that occur in a small quadrat are more ‘important’ at that site than species that only occur in a large quadrat. This method has been demonstrated to provide a robust trade-off between sampling effort and the accurate representation of species abundance (Morrison *et al*. 1995). Nomenclature used in this study follows that of Henderson (2002).

A total of 272 vascular plant species (including subspecies and varieties) belonging to 157 genera in 58 families were recorded. Of the total, 259 species or 95.2% were native and 13 species or 4.8 % were naturalised. Although no endangered and vulnerable species listed under the Queensland State Legislation (*Nature Conservation Act 1992* and *State Penalties Enforcement Act 1999*) was recorded, *Elacholoma hornii*, listed as a rare species, was found during the survey. *E. hornii* is a small annual herb that was found in regrowth mulga in the Nebine subregion. Queensland Herbarium has only one collection of this species in the Warrego Pastoral District in the past. Therefore, its new location from this project not only extends its distributional range, but also contributes towards ecological knowledge of this poorly known species.

7.3. Before rain and after rain analysis

Given drought-breaking rains occurred during the field work component of the project, we decided to resample 30 of the paired floristic sites (i.e. paired sites in regrowth and remnant mulga) that had been sampled prior to the rain events following the rain. Approximately 60% more plant species were recorded following the rain. However, the number of species significantly varied between the regrowth and remnant sites. There were significantly more species in cleared / regrowth mulga than remnant during drought (plate 4).

Significantly more species were recorded in the cleared / regrowth mulga than in the remnant mulga during drought. But, following good rain, there was no longer a significant difference (Fig. 13). We used multi-dimensional scaling ordination to identify whether there was any significant variation in plant species composition between remnant mulga and regrowth mulga during dry times and remnant and regrowth mulga following rainfall. ANOSIM pairwise tests revealed that the four treatments (remnant in dry times; regrowth in dry times; remnant in wet times and regrowth in wet times) were all significantly different in species composition except for regrowth and remnant mulga following rain; Global $R = 0.35$, $P < 0.001$; Fig. 14).

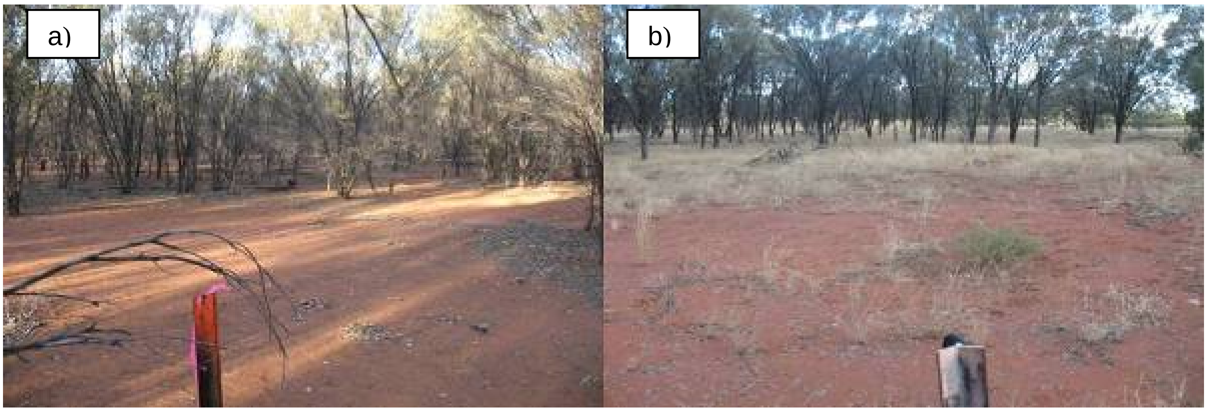

Plate 4: Remnant mulga site a) before drought-breaking rain and b) following drought-breaking rain

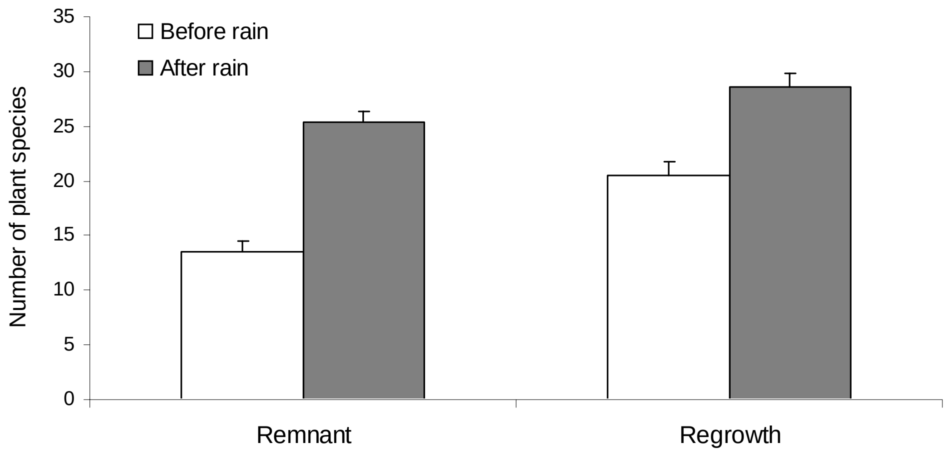

Fig. 13. Number of plant species before rain and following substantial rain for 30 paired sites in remnant and regrowth mulga.

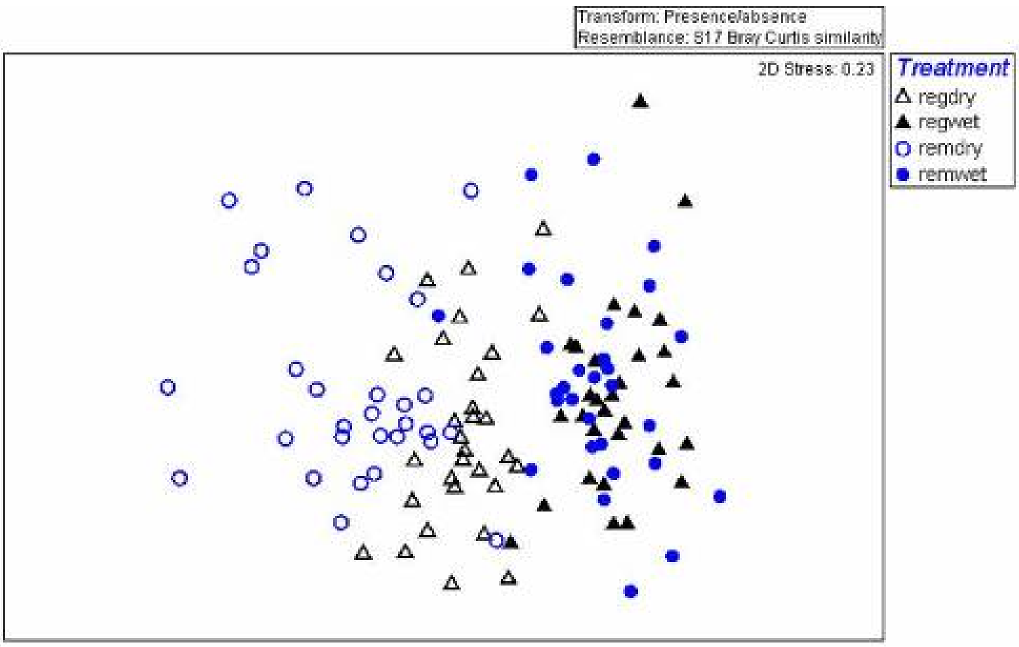

Fig. 14. Multidimensional scaling ordination of plant species assemblages for four treatments; regrowth mulga during dry times (open triangle), regrowth mulga following rain (closed triangle), remnant mulga during dry times (open blue circle) and remnant mulga following rain (closed blue circle).

7.4. Floristic composition in regrowth and remnant mulga

There was no significant difference in species composition between the two remnant subplots i.e. remnant (Ta) and remnant edge (Tb), or the two regrowth subplots i.e. regrowth edge (Tc) and regrowth mulga (Td), suggesting a lack of 'edge effects' in the mulga lands. Consequently, for further analyses, the data from Ta and Tb subplots were combined to represent samples from remnant mulga, and the data from the Tc and Td subplots were combined to represent regrowth mulga samples. Using this dataset, we then looked at whether there was any significant difference in species composition between the six properties sampled (northern properties N1, N2 and N3; central property C1; and southern properties S1 and S2). Using multi-dimensional scaling ordination and pairwise ANOSIM in PRIMER, there was a significant difference between properties (Global $R = 0.587$; $P < 0.001$), with the pairwise tests revealing a significant difference between all the properties, suggesting a management history influence, although the most obvious differences were between the N1, N2 and N3 properties and the C1, S1 and S2 properties, suggesting a biogeographic influence.

We thus applied a non-metric multi-dimensional (NMDS) scaling ordination on floristic abundance data for remnant and regrowth sites collected for each of the six properties separately. We also included data collected from the two properties sampled both before and after the significant rain event (S1 and S2). This analysis revealed that there was no significant difference in species composition between remnant and regrowth sites within each property, except for the two properties sampled prior to the drought breaking rains (Table 3). This substantiates the earlier analysis looking and pre- and post-rainfall data, and again confirms that remnant mulga contains the similar floristic species composition as regrowth mulga, but only after significant rain.

Table 3: Results of NMDS ordination on remnant mulga vector through 2-D solutions when each of the eight property by sampling period combinations are ordinated separately

Property year	Max-R	*P*-value
Property N1 after rain	0.599	0.230
Property N2 after rain	0.703	0.060
Property N3 after rain	0.476	0.270
Property S1 before rain	0.903	0.000*
Property S1 after rain	0.693	0.000*
Property S2 before rain	0.714	0.000*
Property S2 after rain	0.130	0.710
Property C1 after rain	0.221	0.620

8. Mapping mulga vegetation condition states

Relationships between field measured indicators of mulga vegetation condition (from a biodiversity perspective) and available remote sensing products were analysed to assess the efficacy of mapping vegetation condition for a given time period. The objective was to ascertain whether we can monitor change in vegetation condition over the landscape in much the same way as vegetation cover is mapped on an annual basis utilizing current remote sensing imagery (Armston *et al*., 2009). In this study, the field data collected from the 80 stratified sites during March 2007 to May 2008 is matched with remotely sensed data for approximately the same time period.

The methodology and results are provided in Appendix 4. In conclusion, the preliminary investigations into the relationship between site attributes and remotely sensed data show that there is a good relationship between Landsat derived Crown Cover Percent and that measured in the field. Encouraging results were found for stand structure measurements, particularly Stem Density, from the ALOS PALSAR HH and HV polarisation backscatter. Time Since Clearing also proved to be an important attribute in predicting the Total Number of Large Trees recorded at a site. Spatial data on *Time Since Clearing* is available from the Landsat derived Landcover change composite 1988-2007.

An example of a segmentation and classification of the Landsat-derived FPC and ALOS PALSAR HH+HV backscatter products being developed in Definiens Software is provided in Fig. 15. This method is based on the mapping approach developed in Lucas *et al*. (2006). The discrimination of high FPC, low backscatter vegetation from high FPC, high backscatter vegetation permits structural classification of vegetation into above ground biomass classes. The results can be integrated with the Regional Ecosystem mapping (Accad *et al*., 2006) to map regrowth in more detail than is possible use the Regional Ecosystem mapping and FPC products alone.

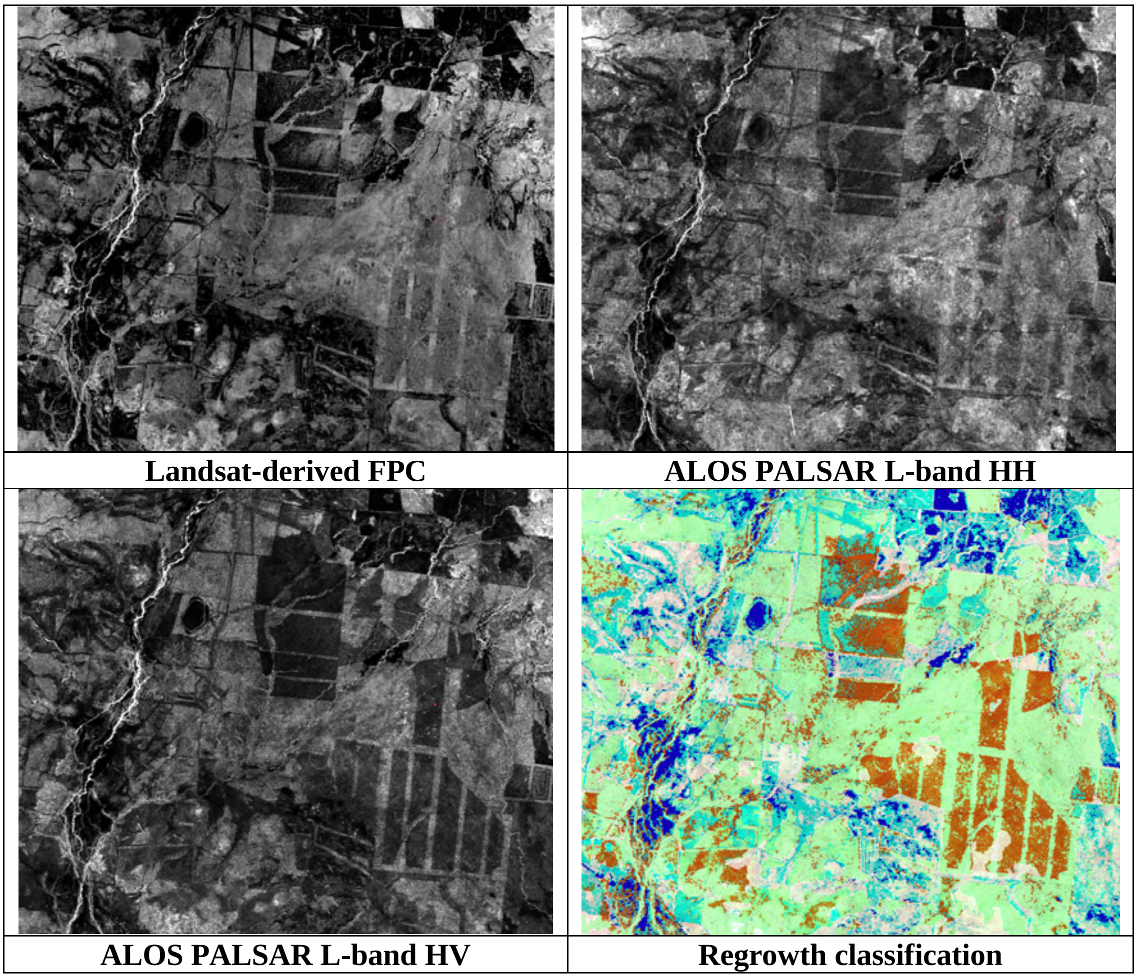

Fig. 15: Preliminary object-oriented classification of low biomass regenerating vegetation in non-remnant areas (orange), remnant vegetation (light green), bare (dark blue), cleared (light blue). White and grey corresponds to unclassified. ALOS PALSAR HH+HV and Landsat-derived FPC were used in the classification – bright areas correspond to high values and dark areas correspond to low values.

9. Landscape function and soil condition

9.1. Methods

Fifty six study sites were located within two landscape level treatments; A 'regrowth within remnant,' and B 'remnant within regrowth'. Within each landscape treatment, paired sites were located within the 'remnant' and, nearby in same paddock but at least 100m from edge of vegetation structures, in 'regrowth' non-remnant mulga. Data was collected from 28 'paired' sites, 56 in total, during two weeks in July 2007. Soil samples from two depths (0-100 mm, 100-200mm) were collected for pH, organic carbon, total nitrogen, phosphorus, soluble salts, chloride contents and particle size analysis; landscape function organisation, nutrient, stability and infiltration indices were derived; measurements of perennial grass basal cover, tree basal area, pasture and soil condition, and ground cover were obtained. The age of regrowth was estimated from aerial photography, land cover change and wide foliage projective datasets. The full methodology, results and discussion are provided in the draft manuscript presented as Appendix 5.

9.2. Results

Clay, sand and silt contents of soils were not significantly (n=56, df=55) different between remnant and regrowth sites (Table 4). These results are typical of loamy and sandy red earth (Mills et al 1990) soils with a sandy clay loam texture (McDonald et al 1990). The concentration of nutrients in upper surface layer (eg Mills et al 1990) was evident in these communities as soil pH, phosphorus, nitrogen and organic carbon contents were all significantly ($P<0.001$) higher in the 0-100 mm labile soil layer.

Table 4: Mean percentages of clay, fine sand, coarse sand and silt for soils sampled from regrowth and remnant sites at 0-100m depth.

Vegetation Structure	Clay (%) 0-10cm	Fine sand (%) 0-10cm	Coarse sand (%) 0-10cm	Silt (%) 0-10cm
Regrowth	25.3	46.2	24.2	5.9
Remnant	23.8	46.2	25.5	6.1

This study found significant differences between vegetation structure and soil characteristics. In the upper surface soil layer (0-100 mm) of remnant sites pH and organic carbon contents were significantly higher ($P<0.1$), and phosphorus ($P<0.001$) and salinity ($P<0.05$) significantly lower, than the regrowth sites. Salinity levels at the 100-200 mm soil depth were also significantly lower at the remnant sites.
Chloride (Cl_mg/kg) measures at the study sites were taken at both depths; however, approximately 70% of samples were below limit of quantitation. Of the measurable samples, mean chloride contents (Cl_mg/kg) at 0-100 mm and 100-200 mm for regrowth (n=33, 47.1; n=18, 46.8 respectively) were higher than remnant (n=9, 43.6; n=6, 28.8 respectively) sites.

Landscape Function Analysis methodology permitted definition of the spatial organisation of runon and runoff zones, their characteristics and quality. Study sites were dominated by runoff areas with bare ground coverage (80%) significantly higher ($P<0.001$) at regrowth sites than remnant sites (60%). The interpatch or runoff areas of regrowth sites had lower potential for cycling of nutrients, water to infiltrate, and less soil surface stability than remnant sites.

Overall, the landscape function results characterise regrowth sites as having significantly higher number, but smaller total area, of ‘log beds with or without shrubs/grasses’ patches; and the greatest proportion of bare ground overall and between these patches where aeolian and fluvian processes dominate in the removal of soil, seed and nutrient resources. The ‘mulga shrub or tree with litter’ patches in remnant areas were fewer in number but had significantly greater area.

Perennial grasses were absent from a quarter of all study sites, and at almost 40% of sites 3P grasses were absent. At sites where perennial grasses were present, these plants were small and sparse, equating to tussock diameter of less than 4cm (DPI&F 2006). Despite perennial grass sparseness, 3P, OP and total perennial grass basal area was significantly higher at regrowth sites.

Percentage of ground cover estimates, ratings for pasture and soil condition and tree basal areas measurements obtained using the Stocktake assessment procedure (DPI&F 2004), varied significantly between regrowth and remnant sites. Remnant sites were treed (tba 4.7 m^2/ha), had better soil condition but worse pasture condition, and greater proportion of ground cover. These results confer with the more quantitative landscape function and perennial grass basal area measurements. An ‘all log bed cover’ of 14% at regrowth sites closely matches the mean ground cover estimate of 15%. There appears to be slightly more error in visually estimating ground cover that is predominately detached litter (21% at remnant sites), compared with the combined total of ‘all log bed cover’ and ‘shrub/tree mulga litter patch’ 15%, than the more discrete log beds.

Estimated age of regrowth sites ranged from 4 to 25 years, with mean of 15 years. For these analyses remnant sites, as they were all largely intact as per 1969 air photos (LWA 2008) and as mulga regrowth can reach remnant status in 15-30 years (Page et al 2008), were included as 30 year old regrowth. As expected, tree basal area increased with increasing regrowth age explaining 46% of the variance. Improvement in soil condition, nutrient and stability index values occurred with increasing regrowth age, with these variables explaining about a third of the variance. Less than 15% of the variation was explained by 3P grass basal area, these grasses significantly decreasing with increasing regrowth age. Decreases in soil phosphorus and salinity, OP and grass basal index; and increases in ground cover%, landscape function organisation and infiltration indices; were significantly, but weakly, correlated with increasing age of regrowth explaining 10% or less of the variation.

9.3. Discussion

Remnant and regrowth soft mulga communities in south-western Queensland differ structurally, functionally and in their productivity. This study has shown differences in landscape organisation of patch, interpatches and functional indices; grass production; and soil organic carbon, phosphorus and salinity contents that indicate tree removal in mulga communities can disrupt key ecosystem processes with both positive and negative impacts.

Some of these changes being sustained as the age of regrowth increases toward that of a remnant community.

Landscape organisation and functional indices

The modified regrowth mulga communities, virtually devoid of a treed overstorey (0.5 tba m^2/ha), were characterised by high percentage of bare ground cover; relatively numerous, but smaller, patches of log beds where perennial grass and shrub cover was greater. The regrowth sites had the potential for greater movement of vital resources from runoff zones that occurred over a greater proportion of the landscape.

Loss of landscape patchiness can reduce the capacity of a landscape to capture rainfall as soil water by 25%, which in turn reduced net primary productivity by about 40%, having a greater impact than differences in patch pattern (Ludwig et al 1999). Patches are functionally important, particularly in water-driven systems (Burrows 1986) that occur on infertile soils with low water holding capacity (Walker and Fogarty 1986), in controlling the amount and availability of water, and enhancing soil infiltration and capture of scare materials (Ludwig and Tongway 1995). The potential for resource capture, increased infiltration and higher capacity for internal recycling of nutrients (Ludwig and Tongway 1995) is similar for both regrowth (log bed) and remnant (shrub/mulga litter) communities as patches covered approximately 14% of the community landscapes.

Although the regrowth sites have more poorly functional runoff areas, resource losses out of the system were greatly reduced by the log bed patches, in similar proportion to those at remnant sites. It is likely that the same conclusions, coupled with the knowledge of landscape function principles, could have been drawn from the visual estimates of ground cover for regrowth (15%) and remnant (21%).

Perennial grass cover

In the mulga communities, perennial grass cover was sparse and plants, when present, were small. Regrowth mulga, with log bed patch resource reservoirs, had significantly higher perennial, palatable and productive grasses; other grasses; and total grass cover. The removal of mulga trees enhances germination of seedlings and improves grass cover by reducing the competition for water and nutrients (Burrows 1986, Beale *et al.* 1986); causes soil disturbance that increases germination after first rains (Silcock 1973); and provides litter and depressions where moisture accumulates (Pressland 1984). The low grass cover in remnant sites concurs with yields found in other mature mulga ecosystems (Burrows 1976).

Soil chemistry dynamics

Changes in soil pH and organic carbon, phosphorus and soluble salt levels following disturbance to the mulga communities were evident in this study. The significance of more acidic soils (4.84) in the upper soil layer at regrowth sites than remnant soils (4.96) is not clear; however, the acidic low pH (<5.8) conditions at both communities may be affecting plant growth (Mills et al 1990).

As organic matter, and hence organic carbon, has important functions in soils (Baldock and Skjemstad 1999), the significantly higher soil organic carbon levels can provide remnant mulga sites with larger reservoir of nutrients, and improved soil structure, infiltration and water-holding capacity. Large reductions in organic carbon inputs can be expected at regrowth sites with very low tree density (Harms et al 2005) and minimal litter

ground cover. The lower soil organic carbon levels at regrowth sites are due to the combined effects of reduced inputs and increased microbial mediated decomposition that follows disturbance of naturally forming surface crust. Total nitrogen levels, although slightly lower in regrowth soils, were not significantly different. Harms et al (2005) found mean soil N stocks at cleared sites were lower, though not significantly, than at uncleared sites, and changes in soil C were associated with similar changes in soil N.
Phosphorus (P) was significantly lower in remnant soils at both 0-100 mm and 100-200 mm depth, with mean extractable P levels from upper soil layer in regrowth (4.36) and remnant (3.59) are within range of red earths and sandy red earths measured by Mills et al (1990). Phosphorus (P), a very stable or insoluble element (Holford 1997), is the main limiting plant nutrient in Queensland mulga soils (Walker and Fogarty 1986). Labile organic P fraction, measured using the bicarbonate extraction method, is readily mineralised and made available to plants almost exclusively by soil micro-organisms (Richardson 1994). The higher soil P levels in regrowth mulga are a result of increased mineralisation of labile organic P subsequent to disturbance (Richardson 1994) of soil surface crust, that improved infiltration and soil conditions for microbial activity. Rate of P supply to plants in remnant communities is much lower than that of regrowth, with remnant mulga communities reflecting a balanced system where continued inputs of P (plant or animal residues) are matched by the rate of depletion (decomposition and mineralisation).

Soft mulga soils have inherently low salinity, or presence of soluble salts, and chloride contents (Pressland 1984, Walker and Fogarty 1986); however, the presence of soluble salts, and their effect on osmotic suction in reducing the amount of moisture available to plants, is particularly relevant to an environment where soil moisture is low (Mills *et al.* 1990). Salinity levels at regrowth sites were significantly higher than at remnant sites. Lower salinity levels in treed remnant areas are due to the influence of deeper root zones (where salts accumulate as result of evapotranspiration processes) that mobilise soluble salts to deeper subsoil layers. A loss of the deeper rooted mulga, and the influence of a low rainfall and high evaporation environment, promoted the accumulation of salt from incoming water in the shallower rooted regrowth vegetation. The increased presence of soluble salts in the upper soil layers, indicates that the improved infiltration of water following disturbance is not penetrating beyond the shallow root zone of grasses, may be limiting the amount of water available to plant growth (grasses in particular).

Age of regrowth

As age of regrowth increased, soil condition (visually estimated) improved, and bare soil surface was more stable and had higher potential for nutrient cycling. Significant patch landscape organisation indices, and ground cover, could explain less than 10% of the variation in age of regrowth suggesting that the functionally important resource sink areas were similarly distributed through all aged mulga communities. Decreasing grass cover, phosphorus (0-100 mm) and salinity levels (0-100 mm, 100-200 mm) were weakly correlated with increasing age of regrowth mulga. Of the weakly significant edaphic measured variables, both phosphorus (0-100 mm) and salinity levels (0-100 mm, 100-200 mm) decreased as age of regrowth increased. The sustained higher soluble salt levels suggest that the regrowth mulga must be at least the mean 15 years or older to attain the deeper root zones of remnant mulga. The lack of any significant correlation between soil organic carbon and age of regrowth, a similar result was found in the study by Harms et al (2005), suggests that the loss of nutrient inputs, and organic carbon, associated with tree removal in younger regrowth communities is relatively quickly compensated for as these communities age.

These significant relationships suggest that the changes to the remnant mulga communities as a result of tree removal are, weakly, sustained as regrowth ages. Presumably, and simply, these positive and negative impacts remain until the significant component of the community (tree basal area) reaches a level that enables the system to function similarly to that of a remnant community.

Mulga is an important and significant component of these communities through its role in nutrient cycling, the hydrological cycle and controlling movement of resources across the landscape. Removal of mulga causes changes to key ecosystem processes with both positive (maintained supply of functionally important patches; improved infiltration, grass production, and plant available phosphorus) and negative (loss of organic carbon, increased soluble salts at the surface) impacts that are primarily sustained as the age of regrowth approaches that of a mature mulga community.

Whether or not the return of a regrowth community to a ‘remnant’ state is a desired outcome, or indeed possible (Page et al 2008), is a mute point to be deliberated in other forums. More importantly, is the on-going management required to ensure sustainable use of regrowth mulga communities that have important functional roles in the modified landscape of the mulga lands. It is widely accepted that mulga lands exists in multiple states (eg. Westoby *et al.* 1989, Jones and Burrows 1994) with transition between them being related to the complex interaction of climate, grazing, fire and other disturbances associated with management (Page et al 2008). Sustainable use of mulga communities, particularly following disturbances, is dependent on maintenance of ground cover that minimises the risk of increases in runoff, sheet erosion and unpalatable woody shrub cover (Pritchard and Mills 1986, Mills 1986, Mills 1989, Jones and Burrows 1994). Awareness, and possible minimisation, of the negative impacts of the tree removal, whilst maximising the productivity gains is the delicate balance that managers need to attain. Managing total grazing pressure, particularly in critical times (eg entering and exiting drought), restricting the area of disturbance, and maintaining a mosaic of different aged communities are important considerations for management and the sustainable use of these functionally important regrowth mulga communities.

10. Main messages

- As to be expected, there is variation among bird and reptile species responses to vegetation states at the landscape level
- Species diversity is not an informative indicator in the Mulga Lands.
- Some species are actively excluding / displacing other species (e.g. yellow-throated miners and small passerine bird species)
- Mulga harvesting in the Langlo subregion has not substantively reduced ant species – there is turnover between remnant and regrowth sites but no difference in species richness between them.
- No ant species or functional group significantly indicative of either vegetation condition (regrowth or remnant) or landscape context (patch vs matrix)
- Rainfall is a major driver of ecological response in the region, and it is vital to ensure that all sites sampled for floristics are standardised with regard to the amount of rain received
- Floristic composition in remnant and regrowth sites do differ, but the combination of biogeography, rainfall and historic grazing management appear to be more important drivers.
- Regrowth mulga does not appear to contribute much to the functionality of the landscape from either a biodiversity or productive perspective. We therefore suggest that an aim of management in the Mulga Lands is to ensure large tracts of regrowth mulga do not occur in the landscape.
- From both a biodiversity and productive perspective, lopping of mulga appears to be a low impact management technique.
- New, high resolution remote sensing products (e.g. ALOS PALSAR HH and HV polarisation backscatter) are showing promise for spatial representation of certain habitat and structural features in the mulga landscape. This will assist in property planning.
- Removal of mulga causes changes to key ecosystem processes with both positive (maintained supply of functionally important patches; improved infiltration, grass production, and plant available phosphorus) and negative (loss of organic carbon, increased soluble salts at the surface) impacts that are primarily sustained as the age of regrowth approaches that of a mature mulga community.
- Managing total grazing pressure, particularly in critical times (eg entering and exiting drought), restricting the area of disturbance, and ensuring a mosaic of different aged communities are important considerations for management and sustainable use of regrowth mulga communities.

11. Impact and influence for Native Vegetation and Biodiversity Program

Major communication achievements by the project team since Milestone 7 include:

1. Scientific papers presented (or to be presented) at Ecological Society of Australia conference, Sydney December 2008; INTECOL conference, Brisbane, August 2009 (see Appendix 6).

Other Knowledge and Adoption (K&A) or Impact and Influence activities conducted since Milestone Report 7 reporting of K&A activities are provided in Appendix 7.

12. References

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Attachments and appendices

Appendix 1: Draft manuscript on the *Range Extension of* Furina barnardi, to be submitted to the *Memoirs of the Queensland Museum* for publication, Department of Environment and Resource Management.

Appendix 2: Draft manuscript *Effects of vegetation management on bird assemblages in the modified landscapes of the Australian rangelands* to be submitted to Biological Conservation for publication, Department of Environment and Resource Management.

Appendix 3: Draft results: *Invertebrate diversity and ecological function in cleared mulga landscapes*, CSIRO.

Appendix 4: Report on efficacy of using available remote sensing tools for mapping vegetation states in the mulga lands, Department of Environment and Resource Management.

Appendix 5: Draft manuscript *Soil carbon losses and salinity, phosphorus and productivity gains in regrowth mulga communities in south-western Queensland, Australia*, to be submitted for publication, Queensland Primary Industries and Fisheries, Department of Employment, Economic Development and Innovation.

Appendix 6: Poster presented at Ecological Society of Australia annual conference, Sydney, December 2008, Department of Environment and Resource Management.

Appendix 7: Impact and Influence table