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Regeneration of degraded woodland remnants after relief from livestock grazing

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Abstract

Clearing for agriculture has left a mosaic of remnants of native vegetation in a matrix of agricultural land. Protection of these remnants is an important issue in minimising the effects of land degradation and for nature conservation in agricultural areas of Western Australia The first approach to restoration is to remove the disturbing element, and in the case of livestock grazing this requires fencing to exclude stock and allow natural regeneration of the remaining vegetation. The description of this natural regeneration process is an essential first step in developing restoration techniques and management strategies for areas of degraded native vegetation. This article describes the changes in the vegetation for three different vegetation types in degraded woodland remnants in south-west Western Australia after livestock grazing has been excluded for seven years. These include vegetation types characterised by the overstorey species including jarrah (*Eucalyptus marginata*) marri (*Corymbia calophylla*), wandoo (*Eucalyptus wandoo*) and sheoak (*Allocasuarina fraseriana*). Species of the families Poaceae and Asteraceae were dominant in the understorey in grazed remnants for all vegetation types, with the majority of these species being exotics. After seven years, floristic similarity between fenced and grazed plots had decreased while similarity between fenced and ungrazed had increased, in all vegetation types. Native vegetation in jarrah sites have shown the greatest response to cessation of livestock grazing with an increase in species richness and diversity while wandoo and sheoak plots have showed little change. In terms of plant life forms, there was a significant increase in number and cover of native perennial grasses, perennial herbs and shrubs in the fenced jarrah plots. Response of annual species have tended to fluctuate with annual fluctuations in rainfall. There was variation in response to livestock grazing of different vegetation types within these woodland remnants. At a relatively early stage of decline in a remnant, the structure and composition of the native community can be re-established by excluding stock. However, under severe and prolonged grazing, regeneration will be more difficult. These results indicate that the degree of difficulty of restoration will vary for different community types even within the broad category of jarrah and wandoo woodlands. Therefore, when managing for the restoration of remnants of native vegetation, consideration of vegetation type is an important factor.

Introduction

Widespread clearing for agriculture has left a mosaic of remnants of native vegetation in a matrix of agricultural land. Protection of these remnants is an important issue in minimising the effects of land degradation and for nature conservation in agricultural areas of Western Australia (Saunders *et al*. 1987; McFarlane & George 1992; Hobbs & Saunders 1993) and throughout Australia (Landsberg & Wylie 1991; Lamb 1994). The majority of these remnants have been subjected to varying levels of disturbance, including livestock grazing, which compromises their ability to be self-regenerating (Saunders *et al.* 1991) and therefore they are in various stages of degradation. The first approach to restoration is to remove the disturbing element (Lamb 1994) and in the case of livestock grazing this requires fencing to exclude stock and allow natural regeneration of the remaining vegetation. The description of this natural regeneration process is an essential first step in developing restoration techniques and management strategies for areas of degraded native vegetation. Livestock grazing exclusion experiments have been conducted in many different vegetation types in Australia, such as alpine grasslands and heathlands in eastern Australia (Wimbush & Costin 1979; Wahren *et al.* 1994), chenopod shrublands in the semi-arid zone (Graetz & Tongway 1986), temperate shrub-dominated woodlands (Hobbs 1989; Pettit *et al.* 1995) and grassy woodlands (Gibson & Kirkpatrick 1989). These studies indicate that differences in vegetation response to relief from grazing pressure are related to intensity of grazing, history of grazing and vegetation type (Milchunas & Lauenroth 1993) and often the results are not assured (Yates & Hobbs 1997).

Response of individual plant species to grazing varies according to growth form and reproductive strategy. For example, annual species are more tolerant of disturbance, due to their fast growth rates and early and prolific seed set, than perennial species which tend to be comparatively slow growing and usually require several years to reach reproductive maturity (Grime 1974). Other groups such as geophytes can avoid heavy grazing pressure by having above-ground growth occurring in winter and spring, and dying back to an underground storage organ over summer (Pate & Dixon 1981) when grazing pressures are usually heaviest. It may also be useful in ecological terms to suggest the regenerative capacity of a plant community according to species functional groups (Hobbs 1992) is based on life forms or reproductive strategies (Armstrong 1993). Maintenance of one or more species representative of each functional group may be an important strategy in restoration/ management of degraded remnants (Hobbs 1992).

In south-west Western Australia, jarrah (*Eucalyptus marginata*) woodland comprises many different plant communities distinguished by the structure and composition of the understorey (Havel 1975). These differences are usually related to soil type and moisture regime (Bell & Heddle 1989). Whether these different plant communities demonstrate the same response to degradation by livestock grazing and capacity for recovery after the exclusion of stock is unknown. Differences in response have important implications for the management for restoration of these remnants.

Pettit *et al.* (1995) examined the floristics of a large number of jarrah woodland remnants subjected to varying levels of livestock disturbance. This paper reports on the natural regeneration of three different vegetation types in degraded jarrah woodland remnants in south-west Western Australia after livestock grazing has been excluded for seven years. These include vegetation types characterised by the overstorey species jarrah (*E. marginata*); marri (*Corymbia calophylla*); wandoo (*Eucalyptus wandoo*) and sheoak (*Allocasuarina fraseriana*).

Methods

Study sites were located within remnants of native vegetation near the town of Darkan in the south-west of Western Australia (33° 30' S, 116° 30' E) where approximately 67% of the native forest has been cleared for farmland (Loh *et al.* 1989). The landscape and soils of these sites are typical of the Beraking Valley form, with slopes dominated by gravely sandy soils with some ferruginous duricrust on the hilltops (Mulcahy & Bettenay 1972). The sites are at the eastern extent of the northern jarrah forest where jarrah and to a lesser extent marri and wandoo form a woodland or open forest (Dell & Havel 1989). There is a mid-storey of small trees such as *A. fraseriana, Banksia grandis* and *Persoonia longifolia,* and the understorey is dominated by perennial woody shrubs and herbs with the most abundant families being Proteaceae, Papilionaceae, Myrtaceae and Cyperaceae (Bell & Heddle 1989). The climate of the study region is Mediterranean-type with long term average annual rainfall of between 650 - 700 mm yr^{-1} of which approximately 80% falls between the months of May and October. At a nearby (10 km) climate station, over the study period low rainfall years were recorded in 1994 with 451 mm yr^{-1} and 1997 (401 mm yr^{-1}). Higher than average rainfall was recorded in 1992 (717 mm yr^{-1}) and 1996 (753 mm yr^{-1}).

This region contains many remnants of native vegetation of varying size and composition, in a matrix of agricultural land (60% cleared) which is principally maintained for sheep pasture with some cropping. All three chosen vegetation types have a shrub dominated understorey and are characterised by the dominant overstorey species. They include; jarrah and some marri which tend to occur in the mid- to up-slope landscape positions on lateritic gravelly soils in a sandy loam matrix; wandoo which occurs in the shallow valley bottoms on heavier soils; sheoak with an overstorey of jarrah and marri which occur on mid-slopes in sandy soils. For this study, a remnant degraded by continuous livestock grazing was chosen for each vegetation type. Remnants varied in size from 10 to 30 hectares and all of these remnants have been continuously grazed by sheep for at least the last 10 years at stocking rates of approximately 5 sheep per hectare. Grazing pressure tends to be heaviest in summer when there is little feed in the surrounding pasture. For each degraded remnant of each vegetation type, there was a nearby area of intact vegetation that had not been disturbed by livestock grazing, usually separated by a fence or road. Ungrazed remnants of equivalent size to the grazed remnants do not exist in the study area so that ungrazed plots were in larger areas of native vegetation but situated adjacent to cleared agricultural land so that plots would be subjected to similar edge effect disturbances (see Saunders *et al.* 1991).

In grazed remnants of each vegetation type, three paired replicate 10 m x 10 m plots were established. For each pair of plots, one was fenced with a sheep-proof ringlock fence, while the adjacent plot was pegged out and left open. Fencing was effective in excluding sheep but not rabbits and native herbivores. For each vegetation type a further three replicate plots were marked out in an adjacent remnant that had no livestock grazing disturbance. Therefore, for each vegetation type, there were three types of treatment plot, fenced plots in degraded remnants where livestock grazing was excluded, adjacent grazed plots in degraded remnants where livestock grazing has continued and ungrazed plots of native vegetation which have not been subject to livestock grazing disturbance. This gave a total of nine 10 m x 10 m plots in each vegetation type with three fenced, three grazed and three ungrazed plots. Plots were placed approximately 50 m from the boundary of the remnant to minimise edge effects.

The initial vegetation survey of all 10 m x 10 m fenced, adjacent grazed and ungrazed plots was completed in November 1991 with subsequent surveys being carried out annually in November 1992, 1993, 1994, 1995 and 1997. For each survey, all understorey species occurring within a plot were recorded and relative cover-abundance estimated using the Domin-Krajina scale (Mueller-Dombois & Ellenberg 1974). The presence and cover abundance of only the seedlings of overstorey species were recorded and utilised in further analysis. Species diversity was calculated using the Shannon-Weiner index (H) and Sorensen's index of similarity was used (where scores are between 0 and 1 with a score of 1 indicating complete similarity between plots; Kent & Coker 1992) to indicate the degree of similarity between vegetation types and the different treatment plots. A species importance value was calculated for each species in each vegetation type and grazing regime as relative frequency + relative cover.

To identify the effects of grazing on functional types, species were grouped according to life form (*i.e.* native shrubs, native perennial herbs, native perennial grasses, native geophytes, native annual herbs, exotic annual herbs and exotic annual grasses). For the purpose of comparing fenced, grazed and ungrazed plots, cover abundance values were transformed to give equal weighting to each Domin scale class so that plot averages could be calculated. Transformation used the method described by Bannister (1966) where the mean of the combined cover and frequency values can be used to give a transformed linear scale according to y = 0.0428 x.

Results

The ungrazed remnants for each vegetation type are dominated (in terms of number of species) by the families Papilionaceae, Asteraceae and Poaceae including 16 species in the ungrazed wandoo site (Table 1). This is partly due to invasion by exotic weeds. This invasion of weeds is mostly due to other disturbances related to the isolation of remnants such as altered fire regime, increased exposure, and nutrient enrichment (Hobbs & Atkins 1988; Cale & Hobbs 1991; Saunders *et al.* 1991).

In the ungrazed jarrah site 42 families were represented, of which Papilionaceae and Epacridaceae were the most prominent families of native perennial species. At the ungrazed wandoo site there were 39 families, with Cyperaceae and Goodeniaceae being the prominent native perennials. The ungrazed sheoak site had 34 families with the greatest proportion of native perennials in the Proteaceae and Dillieniaceae (*Hibbertia* spp). Plots in the degraded remnants were also dominated by Asteraceae, Papilionaceae and Poaceae with exotic species contributing a large proportion of species, particularly in the Poaceae (Table 1). The lily family Antheriaceae, consisting of native perennial herbs and geophytes, was also prominent in fenced and grazed plots in all vegetation types. For the degraded jarrah site, Stylidiaceae was common in the fenced plots while Orchidaceae was well represented in the grazed plots. There was also an additional 5 native species of Papilionaceae in the fenced plots compared to the grazed plots. Papilionaceae also features in the degraded sheoak plots but only as exotic annual forbs (*Trifolium* spp).

The Sorensen similarity index indicated the floristic similarity between fenced and grazed, fenced and ungrazed and grazed and ungrazed plots for each vegetation type (Fig 1). The greatest similarity was between fenced and grazed plots in 1991 at the time of fencing. Only the fenced jarrah plots have had a significant decline in similarity over the study period ($r^2 = 0.805$, $P = 0.015$). Comparison between fenced and ungrazed plots indicates that only the jarrah plots exhibited significant change towards greater similarity with ungrazed plots ($r^2 = 0.661$, $P = 0.0493$). Similarity between the fenced and unfenced plots and between the grazed and ungrazed plots for the wandoo and sheoak sites have shown no significant trend over time (Fig 1). Between the ungrazed and grazed jarrah plots there is a steady decline in similarity over time ($r^2 = 0.835$, $P = 0.0069$) which indicates that the grazed plots are continuing to degrade (lose species). The similarity between ungrazed vegetation types was 0.38 between

Table 1

Families with the greatest number of species for each of the vegetation types in plots in the ungrazed, fenced and grazed remnants at the time of the initial survey (1991).

Ungrazed Plots					
Jarrah	**Spp***	**Wandoo**	**Spp***	**Allocasuarina**	**Spp***
Papilionaceae	11 (1)	Papilionaceae	16 (4)	Poaceae	6 (2)
Poaceae	11 (4)	Asteraceae	13 (4)	Asteraceae	5 (1)
Epacridaceae	6	Poaceae	10 (4)	Goodeniaceae	4
Asteraceae	6 (1)	Cyperaceae	6	Dilleniaceae	4
Anthericaceae	6	Goodeniaceae	6	Proteaceae	4
Fenced Plots					
Jarrah	**Spp***	**Wandoo**	**Spp***	**Allocasuarina**	**Spp***
Poaceae	17 (10)	Poaceae	18 (12)	Poaceae	17 (10)
Asteraceae	14 (3)	Asteraceae	12 (5)	Asteraceae	10 (3)
Papilionaceae	11 (3)	Papilionaceae	11 (3)	Anthericaceae	7
Anthericaceae	8	Anthericaceae	9	Cyperaceae	4
Stylidiaceae	5	Cyperaceae	6	Papilionaceae	3 (3)
Grazed Plots					
Jarrah	**Spp***	**Wandoo**	**Spp***	**Allocasuarina**	**Spp***
Poaceae	16 (9)	Poaceae	17 (10)	Poaceae	15 (10)
Asteraceae	13 (3)	Asteraceae	15 (5)	Asteraceae	13 (3)
Anthericaceae	7	Papilionaceae	10 (4)	Anthericaceae	4
Papilionaceae	6 (3)	Anthericaceae	10	Papilionaceae	3 (3)
Orchidaceae	4 (1)	Cyperaceae	5	Caryophyllaceae	3 (3)

* number in brackets is the number of exotic species.

jarrah and wandoo, 0.44 between jarrah and sheoak and 0.38 between wandoo and sheoak.

In the fenced jarrah sites there was a trend of increasing species richness over the 7 years with numbers in 1997 similar to the ungrazed site (Fig 2). For the wandoo and sheoak sites there has been little increase in species richness in fenced plots, and species richness is still considerably lower than in ungrazed conditions. Large variance in the degraded remnants (particularly during 1992-93) most likely reflects the fluctuating presence and abundance of annual species as a result of varying annual climatic conditions, principally rainfall. Species diversity shows little trend in the fenced plots for any vegetation type and may therefore be a poor indicator of change with grazing relief due to the influx of exotic species to replace natives and the lack of dominance of any particular species. The generally lower species diversity in degraded remnants compared with ungrazed remnants may reflect the dominance of a few species that are able to tolerate grazing, such as exotic pasture species.

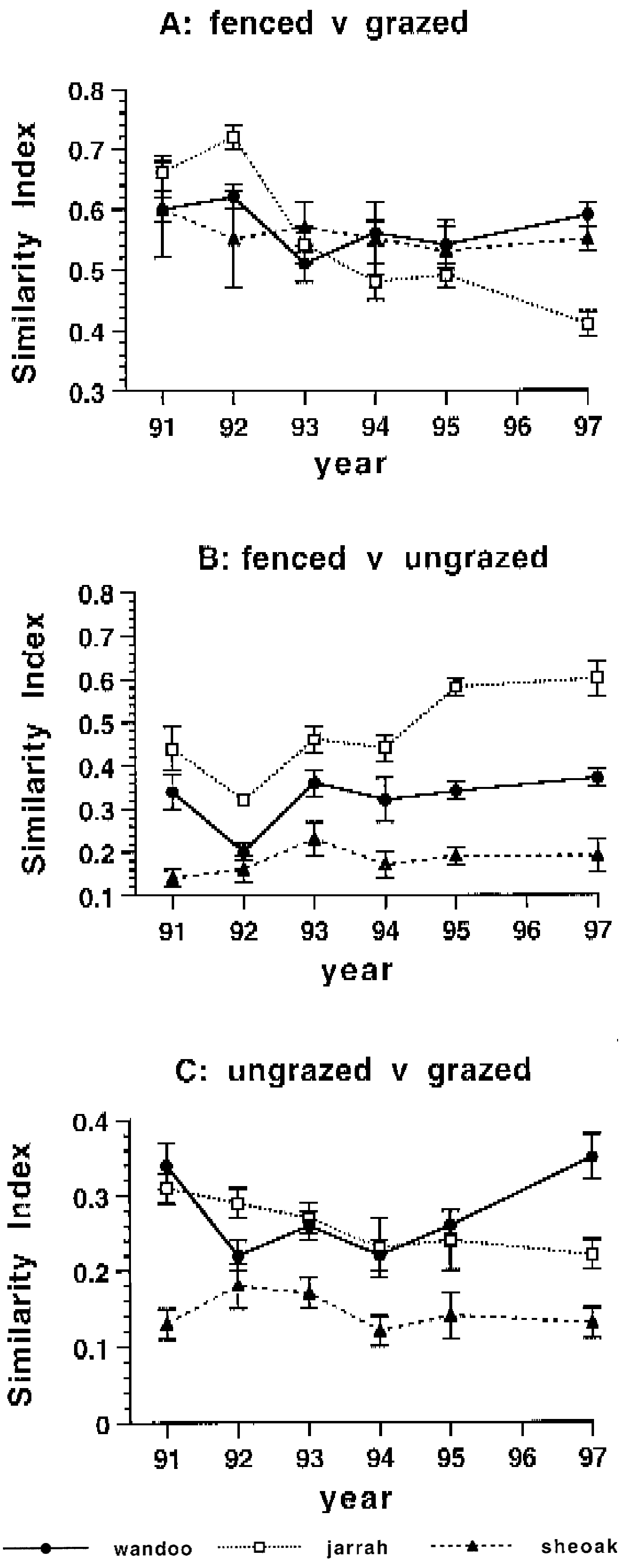

Figure 1. Sorensen similarity index (± se) for comparison of grazed, fenced and ungrazed plots for each vegetation type.

Analysis of species importance shows the dominance of native perennial species in ungrazed plots for all vegetation types, with the 5 most important species contributing from 30% to 40% of the cover (Table 2). In these ungrazed plots, no species are dominant; the only exception is *Dryandra sessilis* in the sheoak plots. In fenced jarrah plots, species importance changed from 4 of the 5 species being exotic annuals in 1991 to 4 of the 5 species being native perennials in 1997. Fenced wandoo plots have continued to be dominated by exotic annual species with only 2 native perennial species becoming important. Fenced sheoak plots have seen the introduction of only one native perennial shrub (*Hibbertia montana*) and continue to be dominated by exotic annual species with the native perennial grass *Neurachne alopecuroidea* becoming important. Grazed plots for all vegetation types are dominated by species such as the exotic annual grass *Aira caryophyllea* and the exotic pasture species *Trifolium campestre* with only the native perennial grasses *Microlena stipoides* (jarrah plots) and *Stipa semibarbata* (sheoak plots) and the native perennial herb *Lagenifera huegelii* being numerically important.

Categorisation of species according to life form revealed a large increase in cover of native perennial grasses, herbs and shrubs in the fenced jarrah plots (Fig 3). Proportions of cover of native geophytes and native annuals have not changed greatly after 7 years of grazing exclusion. By comparison, in the grazed jarrah plots the overall cover has remained low with fluctuating levels of exotic annual species. In fenced wandoo plots there has also been an increase in cover of native perennial herbs and shrubs but also an increase in cover of exotic annuals (Fig 3). Cover in sheoak fenced or grazed plots has not increased significantly over the study period. Cover for life forms in the ungrazed plots for all vegetation types was dominated by native perennial species (Fig 3). Within the jarrah plots these life forms contribute 93% of the cover and 92% and 95% for wandoo and sheoak respectively. These trends in changes of cover for the different life forms in the study plots were also evident in terms of number of species (Fig 4). This indicates that not only has cover of existing species increased but increases in cover have come from the addition of new species into the fenced plots.

Seedlings of overstorey species were recorded in all jarrah plots for all years, with an average of 5 per year in fenced plots, three in ungrazed plots and one in grazed

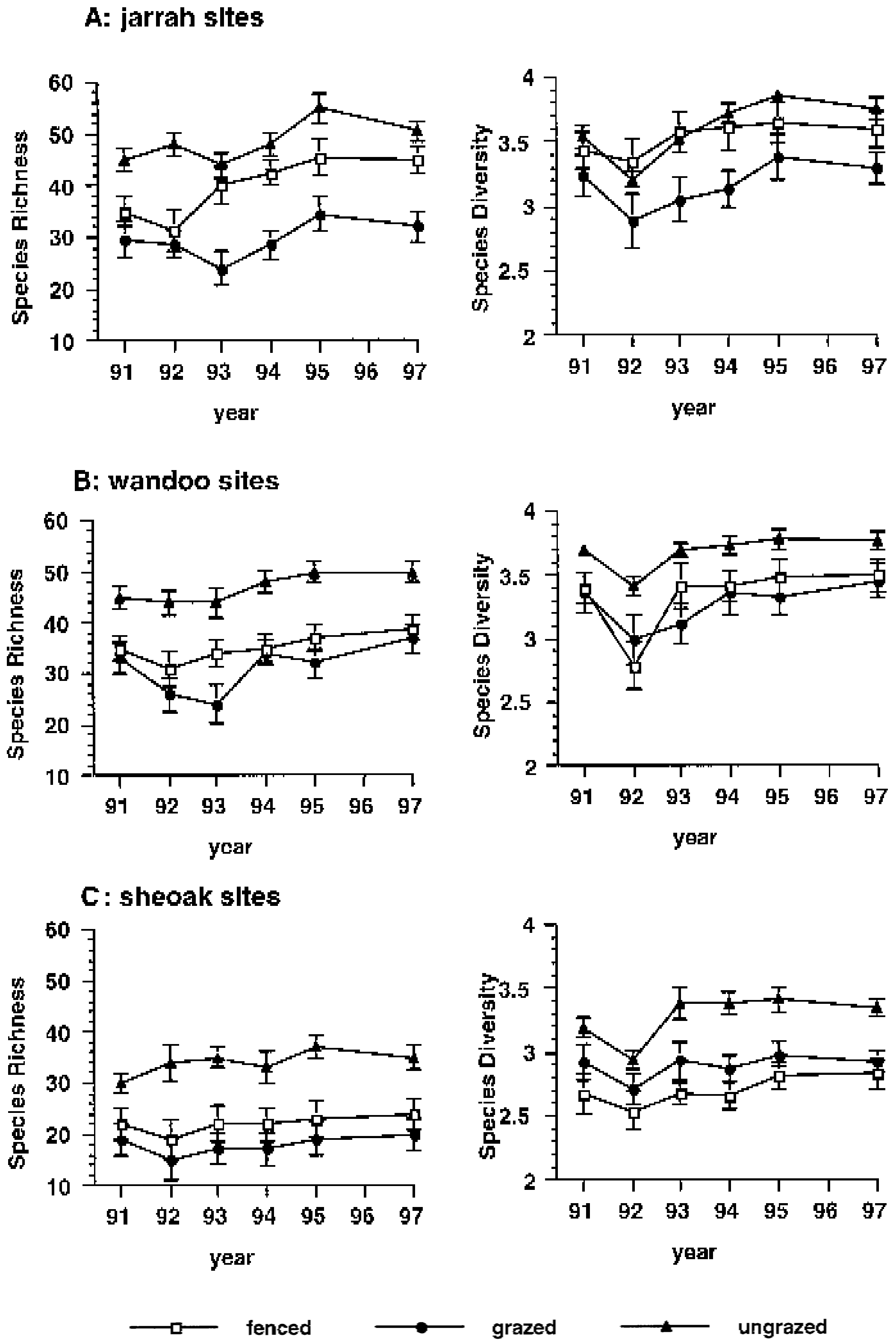

Figure 2. Species richness and diversity (± se) for each of the vegetation types, in grazed, fenced and ungrazed plots over the 7 years of measurement.

Table 2

Species importance value (relative cover + relative frequency) for the 5 highest ranking species for each vegetation type and grazing disturbance recorded for 1991 and 1997.

Ungrazed 1991	Importance value	Ungrazed 1997	Importance value
Jarrah sites		**Jarrah sites**	
Scaevola striata (s)	8.47	*Bossiaea ornata* (s)	12.0
Hakea lissocarpha (s)	7.53	*Lepidosperma gracile* (ph)	12.0
Bossiaea ornata (s)	5.65	*Scaevola striata* (s)	10.3
Trymalium ledifolium (s)	5.65	*Loxocarya fasiculata* (ph)	6.19
Lepidosperma gracile (ph)	3.77	*Trymalium ledifolium* (s)	4.47
Wandoo sites		**Wandoo sites**	
Hakea lissocarpha (s)	11.4	*Lepidosperma gracile* (ph)	10.57
Bossiaea ornata (s)	8.79	*Bossiaea ornata* (s)	10.07
Davesia pectinata (s)	6.72	*Dryandra nivea* (s)	7.89
Lepidosperma gracile (ph)	4.13	*Scaevola striata* (s)	6.88
Hibbertia montana (s)	4.13	*Hibbertia montana* (s)	4.18
Allocasuarina sites		**Allocasuarina sites**	
Dryandra sessilis (s)	29.5	*Dryandra sessilis* (s)	16.72
Bossiaea ornata (s)	8.87	*Bossiaea ornata* (s)	14.49
Hakea lissocarpha (s)	8.87	*Hakea lissocarpha* (s)	14.49
Lepidosperma gracile (ph)	8.87	*Lepidosperma gracile* (ph)	14.49
Glischrocaryon aureum (ph)	8.87	*Glischrocaryon aureum* (ph)	5.02
Fenced 1991		**Fenced 1997**	
Jarrah sites		**Jarrah sites**	
Aira caryophyllea (eg)	22.85	*Lepidosperma gracile* (ph)	10.88
Trifolium campestre (ef)	12.3	*Hypochaeris glabra* (ef)	6.81
Danthonia caespitosa (ng)	11.42	*Scaevola striata* (s)	5.44
Vulpia myuros (eg)	7.91	*Microlena stipoides* (ng)	5.01
Hypochaeris glabra (ef)	5.71	*Gahnia* sp (ph)	5.01
Wandoo sites		**Wandoo sites**	
Trifolium campestre (ef)	26.7	*Trifolium campestre* (ef)	15.67
Kennedia prostrata (s)	8.75	*Bromus diandrus* (eg)	10.3
Aira caryophyllea (eg)	7.44	*Aira caryophyllea* (eg)	9.98
Petrorhagia vellutina (ef)	5.69	*Sollya heterophylla* (s)	6.31
Hypochaeris glabra (ef)	4.37	*Loxocarya flexuosa* (ph)	3.89
Allocasuarina sites		**Allocasuarina sites**	
Hypochaeris glabra (ef)	22.14	*Aira caryophyllea* (eg)	17.65
Vulpia myuros (eg)	19.15	*Trifolium campestre* (ef)	11.67
Aira caryophyllea (eg)	10.17	*Neurachne alopecuroidea* (ng)	11.67
Stipa semibarbata (ng)	9.0	*Vulpia myuros* (eg)	10.94
Helipterum cotula (na)	5.62	*Petrorhagia vellutina* (ef)	10.21
Grazed 1991		**Grazed 1997**	
Jarrah sites		**Jarrah sites**	
Vulpia myuros (eg)	22.76	*Hypochaeris glabra* (ef)	13.83
Aira caryophyllea (eg)	15.52	*Microlena stipoides* (ng)	9.57
Hypochaeris glabra (ef)	11.21	*Aira caryophyllea* (eg)	8.51
Trifolium campestre (ef)	8.01	*Trifolium campestre* (ef)	6.38
Briza minor (eg)	5.17	*Lagenifera huegelii* (g)	6.38
Wandoo sites		**Wandoo sites**	
Trifolium campestre (ef)	12.97	*Aira caryophyllea* (eg)	15.7
Loxocarya flexuosa (ph)	10.57	*Trifolium campestre* (ef)	13.3
Kennedia prostrata (s)	7.75	*Avena fatua* (eg)	11.0
Hypochaeris glabra (ef)	7.52	*Hypochaeris glabra* (ef)	5.89
Aira caryophyllea (eg)	5.64	*Petrorhagia vellutina* (ef)	4.55
Allocasuarina sites		**Allocasuarina sites**	
Stipa semibarbata (ng)	18.42	*Aira caryophyllea* (eg)	26.72
Aira caryophyllea (eg)	11.05	*Stipa semibarbata* (ng)	14.71
Hypochaeris glabra (ef)	11.05	*Vulpia myuros* (eg)	14.71
Vellia trinervis (g)	11.05	*Trifolium campestre* (ef)	10.55
Vulpia myuros (eg)	8.83	*Hordeum leporinum* (ef)	10.1

eg = exotic annual grass; ef = exotic annual forb; g = geophyte; na = native annual forb; ng = native perennial grass; ph = native perennial herb; s = native shrub.

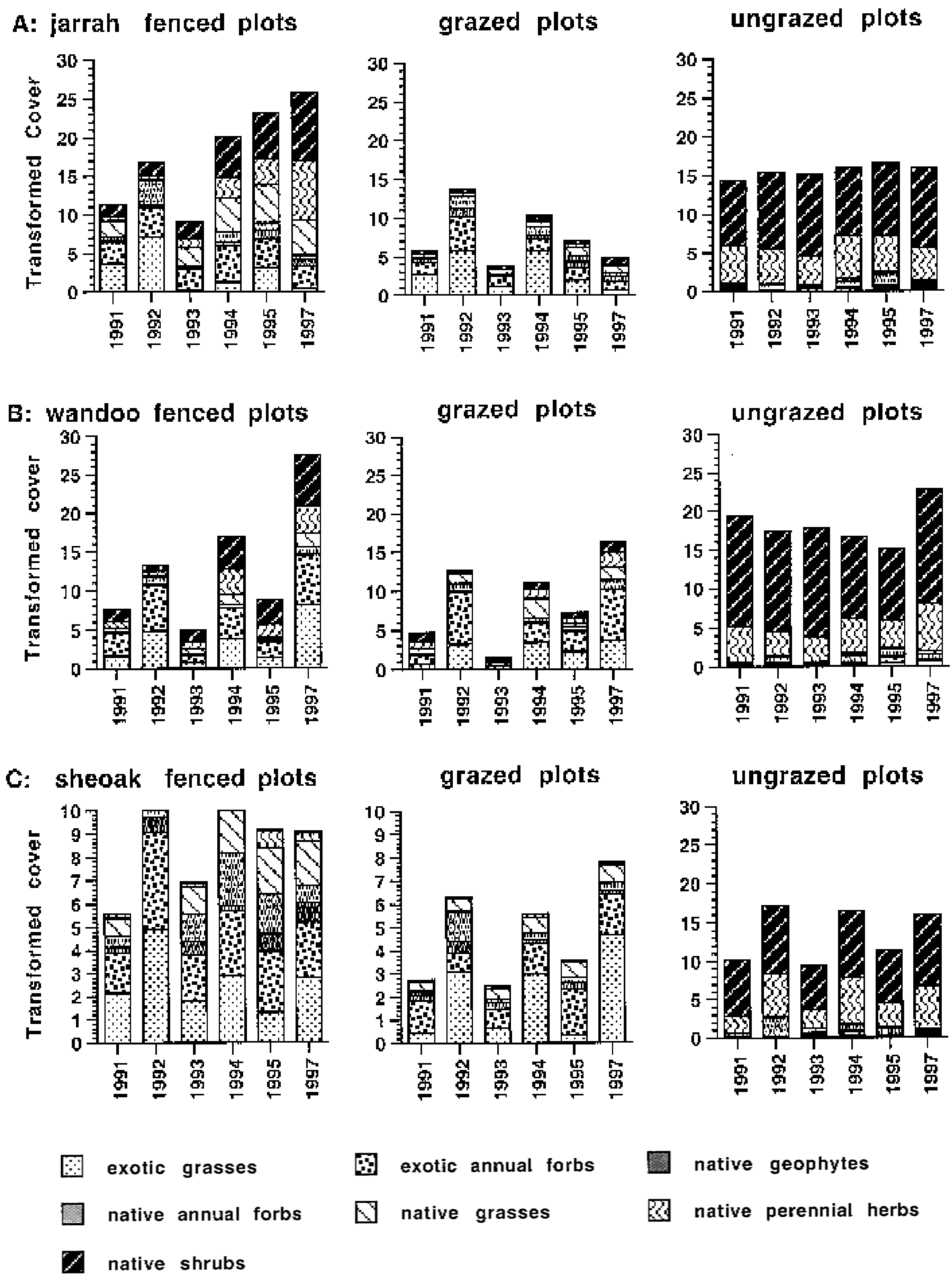

Figure 3. Cover of different life form groups in each of the vegetation types in fenced, grazed and ungrazed plots.

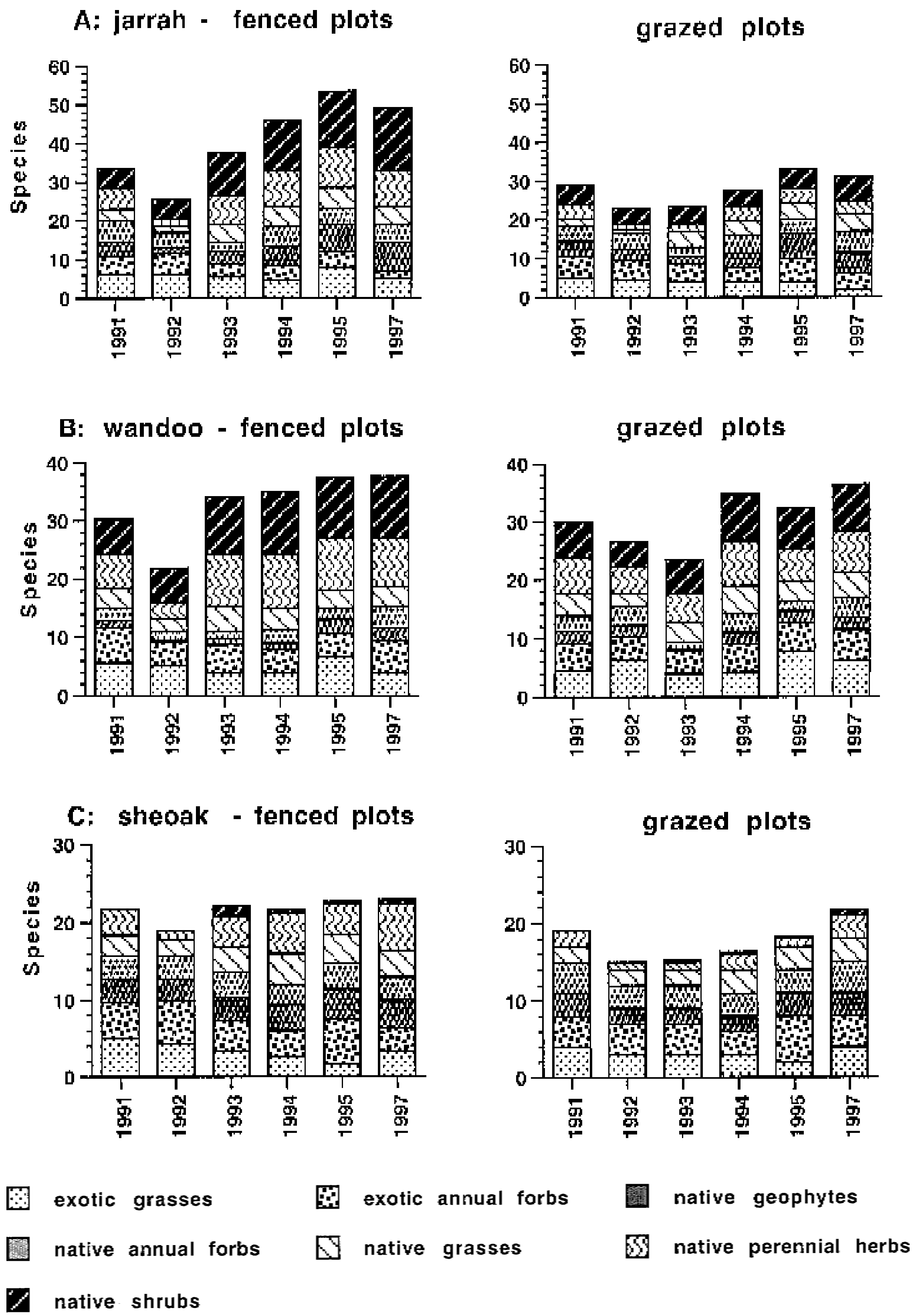

Figure 4. Number of species of different life form groups in each of the vegetation types in fenced and grazed plots. Note the different vertical scale for each vegetation type.

plots. However only at the ungrazed site did seedlings survive into a second or third year. At the wandoo sites, four seedlings were recorded in 1992 in the ungrazed plots; none were recorded in any of the sheoak plots.

Discussion

This study documents the response of the vegetation in degraded woodland remnants in south-west Western Australia, after the cessation of livestock grazing. It also demonstrates the variation in natural regeneration ability of the different vegetation types. Jarrah remnants show a relatively rapid increase in species and vegetation cover of native perennial species after livestock grazing is excluded. Re-establishment of wandoo and, in particular, the sheoak vegetation types, appears to be much slower. However, an important factor in the rate of recovery is the availability of a ready source of reproductive plant material for regeneration. This may come from seed stored in the soil, seed from surviving plants, seed dispersed from surrounding intact vegetation or from vegetative underground storage organs such as a lignotuber which has survived continual grazing of above-ground parts. Our results show that there was a base of existing native perennial taxa in the degraded jarrah remnants and to a lesser extent in the wandoo sites but not at the sheoak sites. Previous work has suggested that on-site soil seedbanks are often not important for natural regeneration of native perennial species in this environment (Vlahos & Bell 1986; Pettit 1995). However, all sites were in close proximity to a source of reproductive material in adjacent ungrazed areas. The mechanisms of seed dispersal from neighbouring sources, such as wind, ants and other vectors, are unclear for most species; however, the species additions recorded at fenced plots were probably derived through seed dispersal. Differences in the ability of native species to re-establish between vegetation types may be due to repression effects on the understorey by both *E. wandoo* (expansive shallow roots; Lamont 1985) and *A. fraseriana* (leaf litter accumulation).

Response of the vegetation to cessation of grazing varies depending on the particular environment, the vegetation type and the grazing history (Milchunas & Lauenroth 1993). In studies of sub-alpine grasslands in eastern Australia, species richness decreased with the exclusion of domestic stock but structural complexity increased (Gibson & Kirkpatrick 1989), herbaceous species and sedges increased in exclosures while shrubs and unpalatable grasses increased in the open plots (Wimbush & Costin 1979) and cover of palatable forbs and shrubs increased substantially with the absence of cattle grazing (Wahren *et al.* 1994). On abandoned farmland in the mallee country in eastern Australia, after initial domination by exotic annuals, some recruitment of understorey shrubs was recorded after 3 years (Onans & Parsons 1980). In *E. salmonophloia* remnants in wheatbelt Western Australia, exclosure plots were dominated by annual exotic species with the regeneration of only one native shrub (Hobbs 1989). The initial increases in annual species in the fenced plots, especially exotic pasture species, have indeed been seen to be only temporary and highly influenced by fluctuations in annual climatic patterns, particularly rainfall distribution and abundance. In remnants degraded by livestock, grazing annual species benefit from grazing due to the increase in area of bare ground that permits establishment and reduces competition from perennial plants which have been removed. The growth phase of annuals is at a time (winter/spring) when there is maximum herbage available, especially in the adjoining pasture, so grazing pressure in remnants is reduced. Other life form groups such as geophytes and native perennial grasses also benefit in this regard because they are unobtainable by livestock during the time of greatest grazing pressure (late summer). The rapid growth of resprouting shrubs and perennial herbs may also make them able to compete successfully with the exotic weeds (Keeley 1986; Hansen *et al.* 1991). However, resprouters need time to recover starch reserves so that they can resprout (Bowen & Pate 1993). Frequent or persistent grazing therefore can exhaust reserves and eventually lead to their loss. Species relying on seed for regeneration can persist only as long as seed is available in the seedbank or is brought in from an outside source. Lack of regeneration of perennial shrubs in the sheoak plots would suggest that possibly the store of perenniating organs and seed has been exhausted.

Germination of seed of overstorey species was recorded in the fenced, grazed and ungrazed plots in this study, but survival of seedlings and saplings has been minimal and only in ungrazed and fenced plots. Greater regeneration of overstorey species may be a factor of parental seed source, favourable climatic conditions and a disturbance creating a recruitment opportunity. Recruitment of jarrah seedlings is enhanced by reduction of soil moisture deficit in late spring and summer, removal of litter and ground cover and some soil disturbance (Stoneman *et al.* 1994). The successful recruitment of wandoo requires a hot fire to create ashbeds for seedling establishment (Burrows *et al.* 1990).

At a relatively early stage of decline in a remnant, the structure and composition of the native community can be re-established by excluding stock. However, under severe and prolonged grazing, the lignotuber bank of resprouters and the seedbank of seed regenerators has been lost and regeneration will be more difficult. Our results indicate that the degree of difficulty will vary for different community types even within the broad category of jarrah and wandoo woodlands. Therefore, consideration of vegetation type is an important factor when managing for the restoration of remnants of native vegetation. This also raises the question of whether intervention such as reseeding, replanting or weed control is required to enhance the natural regeneration process. Natural regeneration may still take place in communities such as the wandoo and sheoak remnants but may take much longer to become evident. The duration of livestock exclusion monitored in this study (7 years) is still a relatively short period, especially if recruitment is episodic and requires a confluence of climatic and disturbance factors. Continued long term monitoring is required to assess this.

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