Exotic plant invasion and understorey species richness: a comparison of two types of eucalypt woodland in agricultural Western Australia

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Exotic plants are a major threat to native plant diversity in Australia yet a generic model of the invasion of Australian ecosystems by exotic species is lacking because invasion levels differ with vegetation/soil type and environmental conditions.

This study compared relative differences in exotic species invasion (percent cover, spp. richness) and the species richness of herbaceous native plants in two structurally very similar vegetation types, Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands in the Western Australian wheatbelt. For each woodland type, plant variables were measured for relatively undisturbed woodlands, woodlands with >30 years of livestock grazing history, and woodlands in road-verges.

Grazed and road-verge Gimlet and Wandoo woodlands had significantly higher cover of exotic species, and lower species richness of native plants, compared with undisturbed Gimlet and Wandoo. Exotic plant invasion was significantly greater in Gimlet woodlands for both grazed (mean 78% cover) and road-verge sites (mean 42% cover) than in comparable sites in Wandoo woodlands (grazed sites 25% cover, road-verge sites 19% cover). There was no significant difference in the species richness of exotic plants between Wandoo and Gimlet sites for any of the three situations.

Mean site richness of native plants was not significantly different between undisturbed Wandoo and undisturbed Gimlet woodlands. Undisturbed woodlands were significantly richer in plant species than grazed and road-verge woodlands for both woodland types. Grazed and road-verge Wandoo sites were significantly richer in plant species than communities in grazed and road-verge Gimlet. The percent cover of exotics was negatively correlated with total (native) plant species richness for both woodland types (Wandoo $r = -0.70$, Gimlet $r = -0.87$). Of the total native species recorded in undisturbed Gimlet, 83% and 61% were not recorded in grazed and road-verge Gimlet, respectively. This compared with 40% and 33% for grazed and road-verge Wandoo, respectively. Grazed Wandoo and grazed Gimlet sites had significantly fewer native plant species than did road-verge Wandoo and road-verge Gimlet sites. Ecosystem implications of differential invasions by exotic species, and the effects of grazing (disturbance) and other factors influencing susceptibility to exotic plant invasion (landscape, competition and allelopathy) on native species decline are discussed. Exclusion of livestock and adequate methods of control and prevention of further invasions by exotic plants are essential requirements for the conservation of these woodland systems.

Key words: Exotic Plant Species, Gimlet *Eucalyptus salubris* Woodland, Invasion, Native Herbaceous Plants, Species Richness, Wandoo *E. capillosa* Woodland, Western Australia.

INTRODUCTION

THE current concern about "biodiversity" is, in essence, one about retaining viable populations of native species of plants and animals (and the genetic material contained in them), and their habitat (Franklin 1993; Recher 1993). Native plant diversity has declined at all geographical scales, largely as a result of the interacting factors of clearing, livestock-grazing and the invasion of exotic plant species (Hobbs and Hopkins 1990; Soulé 1990; Wilson 1990; Hobbs and Huennecke 1992). Additional to loss of species are changes in species composition following disturbance (Pettit *et al.* 1995; Prober and Thiele 1995).

The invasion of native ecosystems by exotic plants is a major conservation problem in Australia, with extensive invasions in tropical, arid and mediterranean regions of the continent (Groves 1986; McIntyre 1990; Humphries *et al.* 1993; Adair 1995; Fox 1995). Generally, more is known about the visually dramatic effects on native plant communities of single-species invasions (mostly woody perennials in tropical regions, such as *Mimosa pigra*; Braithwaite *et al.* 1989) than is known about the visually less dramatic multi-species invasions typical of mediterranean-type environments in southwestern and southeastern Australia (Fox 1990). Several studies also show that different plant communities show different levels of susceptibility to invasion (Bridgewater and Backshall 1981; Hobbs and Atkins 1988; Panetta and Hopkins 1991).

The most urgent information required by managers of native vegetation remnants concerns known (measured) susceptibilities of local plant communities to invasion. There is a need for

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knowledge of local effects because there appears to be no generic model of invasibility based on disturbance types since different communities have been shown to respond differently to disturbance (Fox and Fox 1986; Hobbs 1989). Invasions are also largely "individualistic", depending on a combination of factors co-occurring (Panetta and Mitchell 1991; Scott and Panetta 1993).

Plant species or species groups that have been reduced to small fragmented populations are clearly at comparatively higher risk of extinction due to stochastic events than species with large populations and a wide distribution (Menges 1992). Of particular concern to managers are therefore vegetation types, and individual plant species or species groups, that now occur as small fragmented populations as a direct result of past and present land management strategies.

A sound understanding of the susceptibility of different plant communities to invasion, and the associated effects on native species, is important so that threatened plant species or communities can be identified and prioritized for management. Compared to other vegetation types in the central wheatbelt of Western Australia (e.g., heathlands, shrublands), eucalypt woodlands on the nutrient-richer soils are now poorly represented because they were preferentially cleared for agriculture (Beard 1980; McArthur 1993). Their conservation status is of considerable concern, particularly because many such woodlands have been grazed by stock for long periods and are now often severely degraded, with associated effects on native plants and animals (Arnold and Weeldenburg 1991; Hobbs *et al.* 1993; Yates *et al.* 1994; Yates and Hobbs, in press; Pettit *et al.* 1995; Abensperg-Traun *et al.* 1996a). Native vegetation in road verges is also invaded by exotic plants, reducing its conservation value for native plants as well as animals (Cale 1990; Arnold *et al.* 1991; Cale and Hobbs 1991; Panetta and Hopkins 1991). However, several plants endangered in the wheatbelt now occur only or predominantly in road verges (Hopper *et al.* 1990), and the importance of roadside vegetation to nature conservation is increasing in rural communities (Hussey 1991). Also, invasion by exotics is a major factor influencing the success or failure of revegetation programmes (Panetta and Groves 1990; Hobbs *et al.* 1993). Effective control of exotics or, conversely, establishment of vegetation resistent to exotic invasions, would enhance the probabilities of their successful establishment following plantation, and therefore reduce costs of subsequent management (replanting, weed control, etc.). High rates of successful establishment of native plant species would also increase the probabilities of recolonization by native animals (Majer *et al.* 1984; Andersen 1993). Vegetation invaded by exotic plants also poses greater risks of more frequent wildfires because of higher fuel loads, and a resultant further decline in the diversity of native plants (Wycherley 1984; Hopkins and Griffin 1989).

This paper is the full version of a popular article published elsewhere (Abensperg-Traun *et al.* 1996b). It compares the extent of exotic species invasion and the associated species richness of native herbaceous plants for two structurally very similar eucalypt woodland types (dominated by different tree species) in the Western Australian wheatbelt. Invasion levels and species richness of native herbaceous plants were assessed for three situations typical for eucalypt woodland remnants in the study area, and for woodlands in other agricultural regions of southern Australia: (1) relatively undisturbed woodlands, (2) woodland remnants grazed by livestock, and (3) woodlands in road-verges.

MATERIALS AND METHODS

Study area

The central wheatbelt of Western Australia is a wheat- and sheep-farming district with a semi-arid mediterranean climate of hot dry summers and cool wet winters. The study was carried out within a 1 680 km^2 area ~200 km east of Perth, described in detail by Hobbs and Saunders (1991) and Saunders *et al.* (1993). Average annual precipitation in the study area is ~330 mm (Bureau of Meteorology, Perth).

Soil and vegetation characteristics

The two woodland types selected for study were dominated respectively by Wandoo *Eucalyptus capillosa* and Gimlet *E. salubris*. Wandoo generally occurs on the slopes immediately below break-aways on what is widely referred to as the Booraan land-surface unit (McArthur 1993). Soils supporting Wandoo range from acidic to alkaline, and are typically duplex soils of shallow grey sandy clay over white kaolinite clay, with occasional granitic outcroppings or with varying amounts of lateritic gravel on the eroded surface (Beard 1980; McArthur 1991, 1993).

Gimlet is found downslope of Wandoo (on the Merredin and Belka land-surface units) on the alluvial plain with heavy red, brown or grey (alkaline) clayey soils; sub-soils are frequently saline (Beard 1980; McArthur 1991, 1993). Sites for Wandoo and Gimlet were carefully selected to ensure that other tree species such as Salmon Gum *E. salmonophloia*, York Gum *E. loxophleba* and Mallees, multi-stemmed *Eucalyptus* spp., occurred in very low numbers only. Both woodland types are characterized by a patchy shrub understorey and a diverse herbaceous ground layer. For Wandoo, the shrubby understorey consisted mostly of species of *Melaleuca, Acacia, Olearia* and *Allocasuarina*. For Gimlet, common shrubs were species of *Acacia, Melaleuca, Santalum* and *Atriplex*.

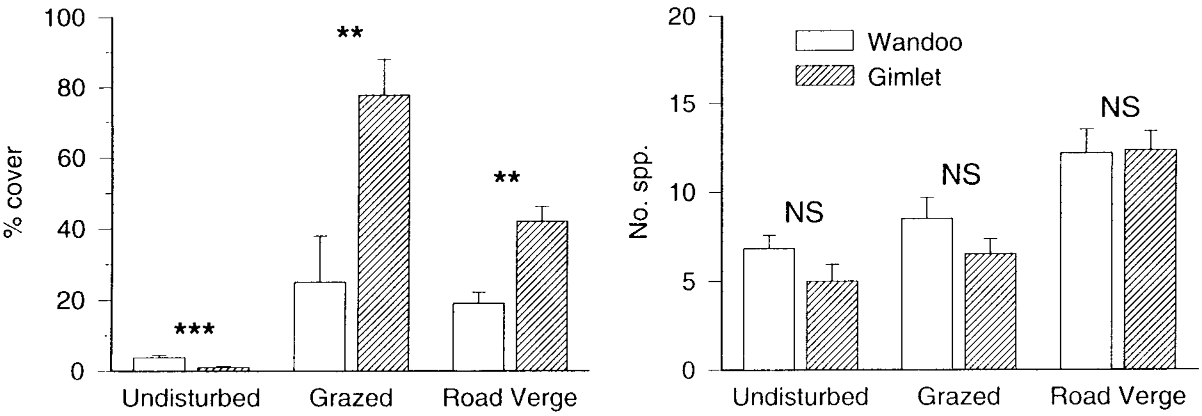

Fig. 1. Percent cover and species richness of exotic grasses and herbs in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands across undisturbed, grazed and road-verge sites (mean ± 1 S.E.; n = 6). **P < 0.01. ***P < 0.001.

Experimental design and sampling methods

In spring (August/September) of 1995, a total of 18 study sites each for Wandoo and Gimlet woodlands were assessed once for exotic plant invasion and species richness of native herbaceous plants. All study sites were in different areas of woodland with different vegetation types between the sites. This ensured that replicates for Gimlet and Wandoo woodlands and respective treatments are true (not pseudo) replicates (Hurlbert 1984). For each woodland type, we sampled across three situations, each with six replicated sites. These situations are typical for plant communities in the study area. (1) Relatively undisturbed sites were located in large and undisturbed remnants, either on nature reserves (Durokoppin, Kodj Kodjin, and North Baandee Nature Reserves) or on private land; study sites had a buffer area of at least 100 m of undisturbed vegetation from agricultural land. Undisturbed sites had no history of livestock-grazing with low levels of selective timber cutting. (2) Sites on small remnants grazed by livestock (sheep) were established 20–30 m away from agricultural land. All grazed Gimlet and Wandoo sites have been under prolonged (>30 years) livestock-related disturbance. (3) Road-verges were 20 m wide and were sampled along transect lines 10 m from agricultural land. Road-verges have been exposed to only light grazing by livestock. For each study site, cover of native and exotic plant species was visually estimated in fifteen 1 × 1 m sample quadrats at 5 m intervals along transect lines.

Data analysis

For native and exotic plants, the statistics calculated for each site were total cover and species richness (total number of species). Species accumulation curves showed that the sampling effort effectively captured native and exotic plant species richness within and between sites and woodland types. One-way analysis of variance was used to test for differences in the site means between disturbance histories and woodland types for plant species richness and percentage cover, and exotic spp. as a percentage of total site richness, using log (x + 1) and arcsine transformed data, respectively. Relationships between cover of exotic species and total exotic and native plant species richness were examined using correlation analyses. Statistically significant differences were accepted if $P < 0.05$.

RESULTS

Exotic plant invasion

Cover

Grazed and road-verge sites for both Wandoo and Gimlet woodlands had significantly higher cover of exotics compared with the undisturbed communities ($P < 0.001$ for all comparisons). Undisturbed Wandoo sites (mean cover 3.8%) had significantly higher cover values than undisturbed Gimlet sites (mean cover 1.0%; $F_{1/11} = 33.48$, $P < 0.001$; Fig. 1). Grazed and road-verge Gimlet woodlands had significantly higher cover of exotics than the equivalent Wandoo woodlands (grazed comparison: $F_{1/11} = 15.94$, $P < 0.01$; road-verge comparison: $F_{1/11} = 12.93$, $P < 0.01$; Fig. 1). There was no significant difference in cover of exotics between grazed and road-verge Wandoo ($P > 0.05$), whereas for Gimlet, cover of exotic species was significantly higher in grazed than in road-verge woodlands ($F_{1/11} = 13.01$, $P < 0.01$; Fig. 1).

Species richness

We recorded a total of 35 exotic species from 12 families and 29 genera (Appendix 1). Origins of exotic species were Europe (14 spp.), southern Africa (12 spp.) and the mediterranean region (10 spp.). The families with the greatest number of exotic species were Fabaceae (nine spp.), Poaceae (nine spp.) and Asteraceae (six spp.). Undisturbed

Table 1. Total number of exotic species recorded across all study sites in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands. Numbers of study sites for each vegetation type are given in parentheses.

	Gimlet woodland *E. salubris*	Wandoo woodland *E. capillosa*
All sites (18)	28	27
Undisturbed sites (6)	9	14
Grazed sites (6)	14	17
Road-verge sites (6)	26	22

and grazed sites for both woodland types had similar numbers of exotic species (P > 0.05), but road-verge sites had significantly higher species richness compared with undisturbed sites for both woodland types (Gimlet comparison P < 0.001, Wandoo comparison P < 0.01). The richness of exotic species was not significantly different between Gimlet and Wandoo woodlands for any of the three situations (Fig. 1; P > 0.05). However, for both woodland types, richness of exotic species showed a tendency to increase from undisturbed to grazed to road-verge woodlands. This was the case for mean site richness (Fig. 1) as well as for the cumulative total richness recorded across all sites (Table 1). Compared to Wandoo sites, exotic species in Gimlet sites represented a higher mean proportion of total site richness (native + exotic spp.) for all situations but only the grazed comparison was statistically significant ($F_{1/11}$ = 9.52, P < 0.05; Table 2). A high percentage of the variation in site richness of exotic species was accounted for by cover of exotics for both woodland types: Gimlet r^2 = 0.77, P < 0.001; Wandoo r^2 = 0.63, P < 0.001.

Table 2. Exotic species as a percentage of total numbers of species for study sites (native + exotic spp.)(mean% ± S.E.). ns = not statistically significant; * = P < 0.05 (ANOVA).

	Gimlet woodland *E. salubris*	Wandoo woodland *E. capillosa*
Undisturbed sites	23.3±2.4	18.9±3.6^{ns}
Grazed sites	85.9±7.6	47.8±11.0*
Road-verge sites	61.5±3.1	45.3±7.2^{ns}

Cover and species richness of native herbaceous plants

We recorded a total of 91 native species from 27 families and 66 genera (Appendix 2). The Asteraceae was by far the richest family, with 23 genera and 31 species (Appendix 2). The total (cumulative) number of native species recorded within a woodland type was higher in Wandoo (73 spp.) than in Gimlet woodlands (57 spp.) (Appendix 2).

Cover of native species was not significantly different for any of the comparisons between

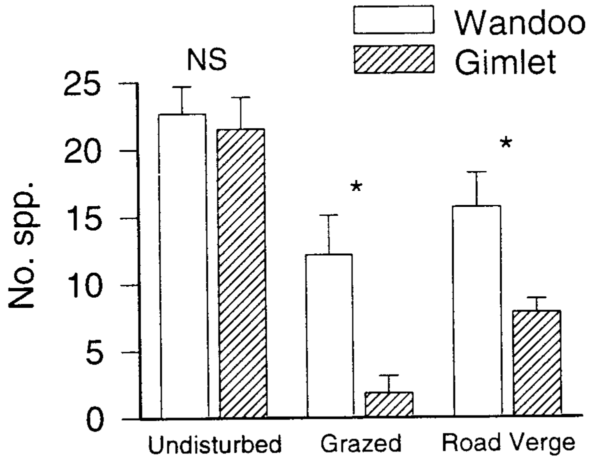

Fig. 2. Species richness of native herbaceous plants in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands across undisturbed, grazed and road-verge sites (mean ± 1 S.E.; n = 6). *P < 0.05.

disturbance histories and woodland types, with the exception of grazed Gimlet where native cover was significantly lower compared with undisturbed Gimlet, but the difference was only marginally significant at P < 0.05. Compared with undisturbed woodlands, there was a highly significant decline in species richness of native herbaceous plants for both grazed and road-verge situations and for both woodland types (Gimlet comparisons P < 0.001; Wandoo comparisons P < 0.01). Mean site richness was not significantly different between undisturbed Wandoo and undisturbed Gimlet woodlands (Fig. 2). The decline in species richness in disturbed sites was significantly higher in grazed and road-verge Gimlet than in grazed and road-verge Wandoo (Fig. 2). As an approximate measure of the loss of native species in disturbed woodlands, the percentage of total species recorded in undisturbed but not in grazed and road-verge Gimlet was double that for the Wandoo comparison (Table 3). The only native species that persisted with some regularity in some grazed Gimlet sites was the Grey Copperburr *Sclerolaena diacantha*.

There was a highly significant negative relationship between percent cover of exotic species and the total species richness of native herbaceous plants, explaining 76% and 49% of plant richness in Gimlet and Wandoo, respectively (Fig. 3).

Table 3. Native plant species that were not recorded in livestock-grazed and road-verge sites (expressed as a percentage of the total native species recorded across all undisturbed sites for respective woodland types).

	Gimlet woodland *E. salubris*	Wandoo woodland *E. capillosa*
Grazed sites	83	40
Road-verge sites	61	33

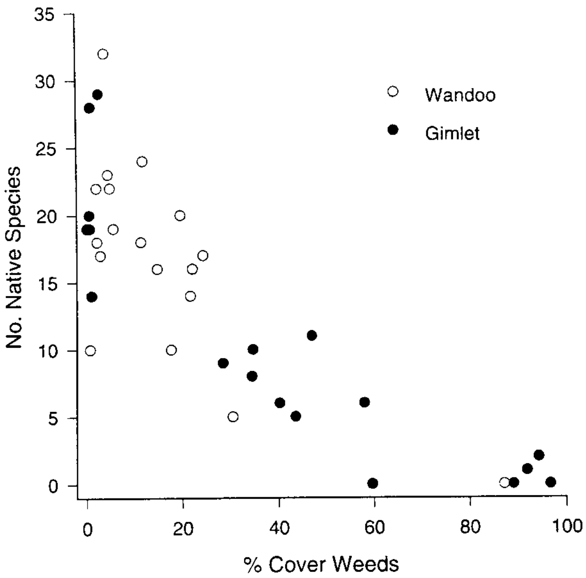

Fig. 3. Relationships between the percent cover of exotic plants and the richness of native herbaceous plants in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands.

DISCUSSION

Susceptibility to invasion

In the Western Australian wheatbelt, heath and shrubland vegetation is more resilient to invasion than are Jam Acacia *A. acuminata* and eucalypt (Wandoo) woodlands, and Wandoo is more resilient to invasion than are these acacia woodlands (Hobbs and Atkins 1988; Panetta and Hopkins 1991; Hester and Hobbs 1992). In addition to these earlier investigations in the study area, the present study demonstrates remarkable differences in exotic plant invasion levels between two structurally similar eucalypt woodlands, Gimlet and Wandoo. Differences in invasion levels (% cover) between the two woodland types were consistent for both grazed woodlands and woodlands in road-verges, with Gimlet showing much higher levels of invasion in both these situations. Grazed sites, however, tended to be more invaded than were road-verge sites, irrespective of woodland type. This is consistent with studies in other parts of Australia which showed increased levels of weed invasion under livestock-grazing regimes (e.g., Prober and Thiele for White Box *Eucalyptus albens* woodlands in south-eastern Australia). The origin of these exotic species is largely consistent with the well-known exchange of species between the different mediterranean regions of the world, southern and North Africa, and Europe (Fox 1990).

Study sites for both woodland types were carefully selected to ensure that they were comparable in terms of grazing history, road-verge width and distance to the agricultural matrix as the invasion source. The observed differences in invasion levels (% cover) between Gimlet and Wandoo woodlands may be attributable to soil differences, or differences in dominant overstory species, and their respective abilities to compete with exotic annuals for moisture and nutrients/minerals, or to chemical inhibition (allelopathic effects). Lamont (1985), for instance, found that annual plants were significantly less abundant underneath Wandoo canopies than in immediately adjacent areas, and he suggested competition for water, rather than allelopathy, as the most probable mechanism of suppression. Chemical inhibition of understorey plants by some eucalypt species is well known (del Moral *et al.* 1978). Tests for chemical inhibition in our study area, for instance, have shown that leachates from Wandoo completely eliminated germination of the exotic *Avena fatua* (Hobbs and Atkins 1991). Thus, low resistance of Gimlet to invasion by annual exotics may in part reflect lack of, or low allelopathic effects on understorey plants. The effects of soil differences between the two woodland types have not been investigated with regard to invasion by exotic annuals.

Native plant species richness

Native vegetation most at risk of invasion includes road-verges (with high edge:area ratios) and habitats grazed by livestock (predominantly woodlands) where physical disturbance (trampling, defoliation) and nutrient inputs both from livestock (nitrogen) and the adjacent agricultural matrix (phosphorus) are known to enhance exotic plant invasion (Hobbs 1991; Cale and Hobbs 1991; Panetta and Hopkins 1991; Hester and Hobbs 1992). The findings of the present investigation support other studies that have shown a marked decline in site richness of native plants associated with increased levels of invasion (Bridgewater and Backshall 1981; McIntyre and Lavorel 1994; Cheal 1991; Cale and Hobbs 1991; Scougall *et al.* 1993). It also showed, however, that the decline in native plant species richness was significantly greater in grazed than in road-verge situations.

Greater decline in native plant species richness in grazed rather than in road-verge woodlands suggests that grazing and/or physical disturbance, in addition to competition with exotics for moisture, light and nutrients, may be an important factor contributing to the decline in plant species richness (McIntyre and Lavorel 1994; Prober and Thiele 1995). Australian plants have not been exposed to, or have not evolved with, grazing pressures by large ungulates to the extent that many European plant communities have, and thus lack their resistance to intense grazing (Hobbs and Hopkins 1990; Wilson 1990; Milchunas and Lauenroth 1993). Consequently, native species subjected to prolonged livestock-grazing rarely survive and are replaced by exotic species that recover well from regular defoliation (Gibson and Kirkpatrick 1989; Cheal 1993; Pettit *et al.* 1995). Examples of exotic species that can sustain high levels of grazing by livestock include *Arctotheca calendula* (McIvor 1972; quoted in Amor and Piggin 1977) and *Hordeum leporinum* (Smith 1966; quoted in Amor and Piggin 1977), which were common in both types of grazed woodland. It is thus not surprising that the combined effects of exotic species invasion and grazing has had more severe effects on native plant species richness than was observed for road-verges where grazing pressure has been low. Also, the establishment of many exotic species is enhanced by physical disturbance (e.g., livestock trampling), with or without elevated nutrient levels (Hobbs 1991).

The extraordinarily high percentage (83%) of native species that were recorded in undisturbed but not in grazed Gimlet woodland remnants is of concern. This concern is compounded by the fact that undisturbed Gimlet now occurs only in small fragmented populations in nature reserves, with the bulk of existing remnants (mostly < 2 ha) lying on private properties. Most of the latter are now severely degraded as a result of prolonged livestock activity and invasion by exotic plants (Arnold and Weeldenburg 1991; Abensperg-Traun *et al.* 1996a,c), and show little if any regeneration of Gimlet, or any other woody native. Surviving Gimlet trees on farm remnants are generally old and senescent. Regeneration by woody perennials as well as native herbaceous plants is unlikely to occur unless sheep are excluded and invasion by exotic plants is controlled (Pettit *et al.* 1995). Even then, however, regeneration may fail without further interventive management (Yates and Hobbs 1997; Hobbs and Atkins, unpubl. data).

Other considerations

The implications of invasion of native ecosystems by exotic plants may extend beyond their immediate effects on native plant species (e.g., Grubb and Hopkins 1986; Panetta and Hopkins 1991). Invasion of native ecosystems can have both positive and negative effects on other biota. Positive effects, for instance, may include an increase in the availability of plants as food for native herbivores. Compared to undisturbed Gimlet woodlands in the study area, for instance, Abensperg-Traun *et al.* (1996a) found that Gimlet remnants with highest levels of exotic plant invasion supported by far the greatest abundance and diversity of beetles (but possibly consisting largely of common disturbance opportunists). This increased abundance and species richness of beetles may be because enhanced soil nutrient regimes, due to fertilizer drift and defecation by stock, leads to more nutritious plant foliage which supports a more abundant, productive and diverse beetle fauna (Ohmart *et al.* 1985; Landsberg *et al.* 1990; Majer *et al.* 1992). Another positive example concerns the rare dasyurid *Sminthopsis virginiae* in northern Australia. The species has benefited from the establishment of dense stands of the exotic shrub *Mimosa pigra* which now provides shelter resembling the mammals' native habitat lost as a result of disturbance by another alien, the Water Buffalo (Braithwaite and Lonsdale 1987). However, available evidence suggests that negative effects of exotic plant invasions on Australia's native biota far outweigh positive influences. We highlight some examples.

A decline in native plant richness and an increase in cover of exotic plants in Gimlet woodlands in the study area has been associated with a significant decline in the species richness of lizards, scorpions and termites (Abensperg-Traun *et al.* 1996a,c). Exotic plant invasion severely reduces the likelihood of regeneration of woody perennials, native shrubs and trees (Wilson 1990). Livestock-grazing reduces the abundance of woody perennials in remnant woodlands invaded by exotics (Scougall *et al.* 1993; Pettit *et al.* 1995). Loss of deep-rooting perennials result in (a) higher recharge rates of often saline ground-waters, and consequent higher levels of soil salinity (McFarlane *et al.* 1993), and (b) higher exposure of the soil surface to the effects of livestock-trampling, wind and water, and hence increased rates of top-soil erosion, and probably soil aridity (Milchunas and Lauenroth 1993). Invasion by exotics may increase the flammability of the vegetation, increasing the risk of wildfires, and result in a further decline in native species richness (Wycherley 1984; Hopkins and Griffin 1989). Loss of native species to infestations by exotic plants may also influence ecosystem function (e.g., nutrient-cycling) and hence a decline in long-term ecosystem resilience (Hobbs *et al.* 1995).

The combination of livestock-grazing and invasion by exotic plants represents one of the most serious threats to the biodiversity in fragmented systems of the Western Australian wheatbelt and one of the biggest problems facing managers of such systems (Adair 1995; Hobbs and Humphries 1995). Exclusion of livestock and adequate methods of control and prevention of further invasions are essential requirements for the conservation of these woodland systems.

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APPENDIX 1

Occurrence of exotic plant species (grasses/herbs) in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands. Origin of species is indicated by [1] = Europe, [2] = mediterranean region, [3] = Southern Africa.

	Gimlet woodland			Wandoo woodland		
Exotic plant species	Undisturbed	Grazed	Rd. verge	Undisturbed	Grazed	Rd. verge
AIZOACEAE						
Mesembryanthemum crystallinum[3]	X	X	X	X	X	X
M. nodiflorum[3]		X	X	X	X	
ASTERACEAE						
Arctotheca calendula[3]	X	X	X	X	X	X
Cotula bipinnata[3]		X	X			
Hypochaeris glabra[1]	X		X	X	X	X
Osteospermum clandestinum[3]			X	X		X
Sonchus oleraceus[1]			X		X	
Ursinia anthemoides[3]				X	X	X
BRASSICACEAE						
Brassica tournefortii[2]	X	X	X		X	X
Sisymbrium orientale[1]		X	X			
FABACEAE						
Lupinus cosentinii[2]		X				
Medicago truncatula[2]	X	X	X		X	X
Trifolium arvense[1]						X
T. campestre[1]			X			
T. cherleri[2]			X			X
T. glomeratum[1]			X			
T. subterraneum[2]		X			X	X
T. tomentosum[2]						X
Vicia sativa[1]			X			
GERANIACEAE						
Erodium botrys[2]			X		X	X
IRIDACEAE						
Gynandriris setifolia[3]			X			X
MALVACEAE						
Malva parviflora[2]		X	X		X	X
OXALIDACEAE						
Oxalis pes-caprae[3]			X			
POACEAE						
Aira caryophyllea[1]				X	X	
Avena fatua[2]	X		X	X		X
Bromus madritensis[1]			X			X
B. rubens[2]	X		X	X	X	X
Ehrharta longiflora[3]						X
Hordeum leporinum[1]		X	X		X	X
Lolium perenne[1]		X	X	X	X	X
Pentaschistis airoides[3]	X		X	X	X	X
Vulpia myuros[1]	X	X	X	X	X	X
POLYGONACEAE						
Emex australis[3]		X	X			
PRIMULACEAE						
Anagallis arvensis[1]				X		
SCROPHULARIACEAE						
Parentucellia latifolia[1]				X		
Zaluzianskya divaricata[3]		X	X		X	X

APPENDIX 2

Occurrence of native grasses/herbs in Gimlet *Eucalyptus salubris* and Wandoo *E. capillosa* woodlands. Annuals unless asterisked (*).

Native plant species	Gimlet woodland			Wandoo woodland		
	Undisturbed	Grazed	Rd. verge	Undisturbed	Grazed	Rd. verge
ADIANTACEAE						
*Cheilanthes austrotenuifolia**	X		X	X		X
AMARANTHACEAE						
Ptilotus gaudichaudii	X					
*P. spathulatus**	X		X	X	X	X
P. sp.*	X					
ANTHERICACEAE						
*Arthropodium preissii**	X	X	X	X	X	X
*Borya constricta**				X		X
*Chamaescilla corymbosa**				X		
*Dichopogon capillipes**				X		X
*Thysanotus patersonii**	X					
*Tricoryne elatior**						
APIACEAE						
Daucus glochidiatus	X		X	X		X
Hydrocotyle callicarpa	X			X	X	X
Trachymene cyanopetala	X			X	X	X
T. ornata	X					
Unknown sp.	X	X			X	
ASCLEPIADACEAE						
*Rhyncharrhena linearis**					X	
ASPHODELACEAE						
Bulbine semibarbata	X					
ASTERACEAE						
Athrixia athrixioides	X					
Actinobole uliginosum	X			X	X	X
Angianthus tomentosus			X		X	
Blennospora drummondii	X					
Brachycome iberidifolia				X		
B. perpusilla	X				X	
Calotis hispidula	X	X	X	X		X
Ceratogyne obionoides						X
Chthonocephalus pseudevax	X			X	X	X
Eremophyllum tenellum	X			X	X	X
Gilberta tenuifolia				X		
Gnephosis tenuissima	X				X	
*Helichrysum leucopsideum**				X		
Hyalosperma demissum	X			X		
H. glutinosum (subsp. *glutinosum*)				X		
H. zacchaeus	X					
Lawrencella lindleyi	X			X	X	X
Podolepis canescens	X				X	
P. capillaris (bi-annual)	X			X	X	X
P. lessonii	X		X	X	X	X
Podotheca gnaphalioides				X		
Quinetia urvillei				X	X	
Rhodanthe laevis	X					
R. pygmaea	X		X	X	X	X
R. rubella	X					
Senecio glossanthus	X		X	X		
Schoenia cassiniana	X			X		
Siloxerus pygmaeus	X					
Toxanthes perpusillus	X			X	X	
Waitzia acuminata (var. *acuminata*)	X			X	X	
W. nitida	X			X	X	
BRASSICACEAE						
*Lepidium rotundum**	X			X	X	
L. sp.*	X					
CAMPANULACEAE						
*Wahlenbergia preissi**				X		

Appendix 2 — continued.

	Gimlet woodland			Wandoo woodland		
Native plant species	Undisturbed	Grazed	Rd. verge	Undisturbed	Grazed	Rd. verge
CHENOPODIACEAE						
Maireana carnosa	X		X			
Maireana sp.*	X		X			X
*Sclerolaena diacantha**	X	X	X		X	X
CRASSULACEAE						
Crassula colorata	X	X	X	X	X	X
C. exserta			X	X		
CYPERACEAE						
Schoenus nanus				X		
DASYPOGONACEAE						
*Lomandra collina**				X		X
*L. effusa**				X		X
DROSERACEAE						
*Drosera glanduligera**				X		
*D. subhirtella**				X		
D. sp.*					X	
GERANIACEAE						
Erodium cygnorum	X	X	X	X	X	X
GOODENIACEAE						
*Dampiera stenophylla**						X
Goodenia berardiana	X		X	X		X
G. sp.				X		
Velleia cycnopotamica	X		X	X	X	X
JUNCAGINACEAE						
Triglochin calcitrapa	X			X		X
LOBELIACEAE						
Lobelia sp.				X		
LOGANIACEAE						
Mitrasacme paradoxa	X					X
OPHIOGLOSSACEAE						
Ophioglossum sp.*					X	X
ORCHIDACEAE						
Caladenia flaccida (subsp. *pulchra**)	X					
*C. flava**					X	
Caladenia sp.*				X		
*Prasophyllum macrostachyum**				X		
*Pterostylis vittata**	X					
OXALIDACEAE						
Oxalis corniculata				X		
POACEAE						
*Amphipogon caricinus**					X	
*Aristida contorta**				X		
*Danthonia caespitosa**			X	X	X	X
*Neurachne alopecuroidea**	X			X		X
*Stipa elegantissima**			X	X	X	X
*S. scabra**				X		
*S. trichophylla**				X		X
S. sp.*	X			X	X	X
PORTULACACEAE						
Calandrinia eremaea	X	X	X	X	X	X
C. polyandra					X	X

Appendix 2 — continued.

Native plant species	Gimlet woodland			Wandoo woodland		
	Undisturbed	Grazed	Rd. verge	Undisturbed	Grazed	Rd. verge
PLANTAGINACEAE						
Plantago sp.	X					
RESTIONACEAE						
Restio sp. *				X		X
STYLIDIACEAE						
Levenhookia dubia						X
ZYGOPHYLLACEAE						
Zygophyllum ovatum	X					

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