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Plant recruitment and survival as indicators of ecological restoration success in abandoned pasture land in Nurcoun, Victoria, Australia

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Abstract

Introduction: One of the major impediments to developing better restoration strategies is the inadequate documentation of past restoration efforts. In 2008, *Greening Australia* commenced ecological restoration on the Nurcoun property in Victoria to enhance local biodiversity, and in this paper we report on the habitat restoration outcomes in the three Ecological Vegetation Classes (EVC) found on this property.

Methods: Permanent sample plots (12 × 20 m) were randomly established in July 2010 in each of the restoration areas, with 9, 10, and 24 plots demarcated in Shallow Sands Woodland (SSW), Heathy Woodland (HW), and Sandstone Ridge Woodlands (SRW), respectively. Individual plots were prepared to include three seeded rows. Plots were assessed for seedling recruitment and survival in May 2010, April 2011, and May 2012. Records of individual seedling development included their height and cover, and their location within the plot.

Results: Our study shows that interaction between the age of the planted and direct-seeded vegetation and the nature of the EVC significantly affects the composition of plants and the soil surface in that species and, further, that soil cover parameters develop in different ways in the different experimental plots. A SIMPER analysis of soil cover parameters shows that most of the variation over the years of restoration is attributable to differences in the amount of bare soil recorded, rather than the amount of leaf-litter cover, and that these changes in soil cover parameters differ between EVCs over the sampling periods.

The direct-seeding study shows that whilst most of the broadcast species were recruited, some species used in the Shallow Sands Woodland, the Heathy Woodland, and the Sandstone Ridge Shrubland did not show evidence of recruitment during the three sampling periods. Although the density of most seedlings increased in subsequent sampling years, the planted species *Callitris gracilis*, *Callitris rhomboidea*, *Hakea muelleriana*, and *Melaleuca lanceolata* did not survive.

Conclusions: As a result of the land use change, new assemblages of abiotic and biotic system components appear to lead to the development of stable alternative ecological states. These 'novel' ecosystems now play an important part of the natural resource base, requiring careful characterization to better understand current development trajectories and future states, and to inform management strategies to meet desired restoration outcomes. Although the study sites have been abandoned for a long time, broadcast seeds and plant seedlings show they can overcome internal resilience.

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Introduction

Intensive human activities and climate change have rapidly and extensively altered the health of natural ecosystems over the past 50 years – more than in any other comparable period (MacDougall et al., 2013; Millennium Ecosystem Assessment, 2005). Given this context, it has been argued that human intervention is now required to counteract or mitigate any further impacts and enhance ecosystem function in these degraded environments (Clewell and Aronson, 2007). Likewise, Suding (2011) recently suggested that habitat restoration is one of the most significant practical opportunities for meeting global conservation goals. In this respect, activities related to the restoration of nature, natural assets, and biodiversity have now become a global concern with an estimated annual budget in excess of \$A1.6 trillion – a figure that is likely to grow substantially in the near future (Merritt and Dixon, 2011).

In Australia (as elsewhere worldwide), federal agencies have invested heavily in a number of restoration projects over the last two decades, whereby, in 2000/2001 alone, \$A36.4 million was allocated to re-establish native vegetation and appropriate wildlife habitats (Wilkins et al., 2003). *Environment Australia's* major on-ground commitments from its \$A27.1 million *Bushcare* funding program included i) the direct seeding of 10,000 ha of degraded land, ii) the planting of 4.5 million seedlings, and iii) the erection of 12,000 km of protective fencing (Wilkins et al., 2003). These figures clearly reflect the overall concern shown for restoration and re-instatement of native ecosystems in Australia. However, despite substantial financial and human investment toward on-the-ground restoration efforts, little has been invested in monitoring of these efforts to assess whether the desired ecological outcomes have been achieved. In fact, in a review by Brooks and Lake (2007), it was reported that of the 2,247 restoration projects undertaken in four catchment areas in Victoria, only 315 (14%) included some form of monitoring, mostly using photographic records. As a consequence, in most restoration projects the on-ground outcome is largely untested, and so planned vegetation restoration strategies are seldom guided by site-specific evidence-based information. Even simple measures, such as the relative performance of broadcast seed and planted seedlings, or the level of natural recruitment of indigenous species, are rarely recorded. Therefore, basic reporting of restoration performance (albeit an unglamorous undertaking) would provide a beneficial insight into landscape-scale restoration successes and challenges which could usefully inform future practices.

One such project is being conducted on the Nurcoung Property, Victoria, Australia. The property was purchased in early 2008 by *Greening Australia*, a not-for-profit environmental organisation formed by the United

Nations Association of Australia and mandated to protect, restore, and conserve Australia's native vegetation. As a result of historical clearing for the purpose of agricultural/pastoral expansion – a typical driver of land-use change in Australia – much of the remnant vegetation in the Nurcoung region is considered fragmented, leaving most of its flora and fauna isolated and vulnerable. The bioregional conservation status of the majority of the ecosystem types contained in these areas are considered to be 'endangered' or 'vulnerable', while the area supports a suite of 'threatened' and 'endangered' species (DEPI, 2013). The property, which is considered to be 'marginal' for agricultural purposes, allowed rehabilitation activities to be initiated in 2009. The intention was to facilitate the movement of small mammal species throughout the landscape by increasing north-south habitat connectivity between the large existing remnant vegetation blocks. This connectivity was considered particularly important for the conservation of fauna because of the significant climate change predictions for this area. Estimations indicate a trend towards higher temperatures and reduced rainfall (Climate Change Victoria, 2012) which would trigger a diminution of the density of required fauna resources in the remnant blocks.

Given the dearth of information about the successes and failures of rehabilitation activities, we have suggested that previous restoration efforts need to be used as 'experimental sites' to gather and subsequently synthesize information that may guide future restoration activities (Holl et al., 2003; Michener, 1997). We therefore used the outcomes of the previous Nurcoung Project to investigate three important restoration trajectory markers, namely i) the possible relationships between the age of restored sites and the levels of seedling recruitment; ii) the level of development of ground cover, particularly leaf litter and soil crusts; and iii) the comparison of the composition and subsequent survival of direct seeding and planting of native plant species. Based on these outcomes, we hope to be able to inform the design and management of future restoration practices in order to redress the damage to ecologically important sites.

Methods

Study Site

The study was conducted at Nurcoung (S 36° 39.834', E 141° 43.990'; WGS 84) located approximately 15 km north-west of Mitre, south of the Little Desert National Park, Victoria, Australia (Figure 1). The property covers a total area of 186 ha of which 56 ha are considered remnant vegetation. Of these, approximately 40 ha had been cleared in the early 1950s and allowed to regenerate naturally; the remaining 130 ha were utilized for cropping and sheep grazing for the 50 years preceding

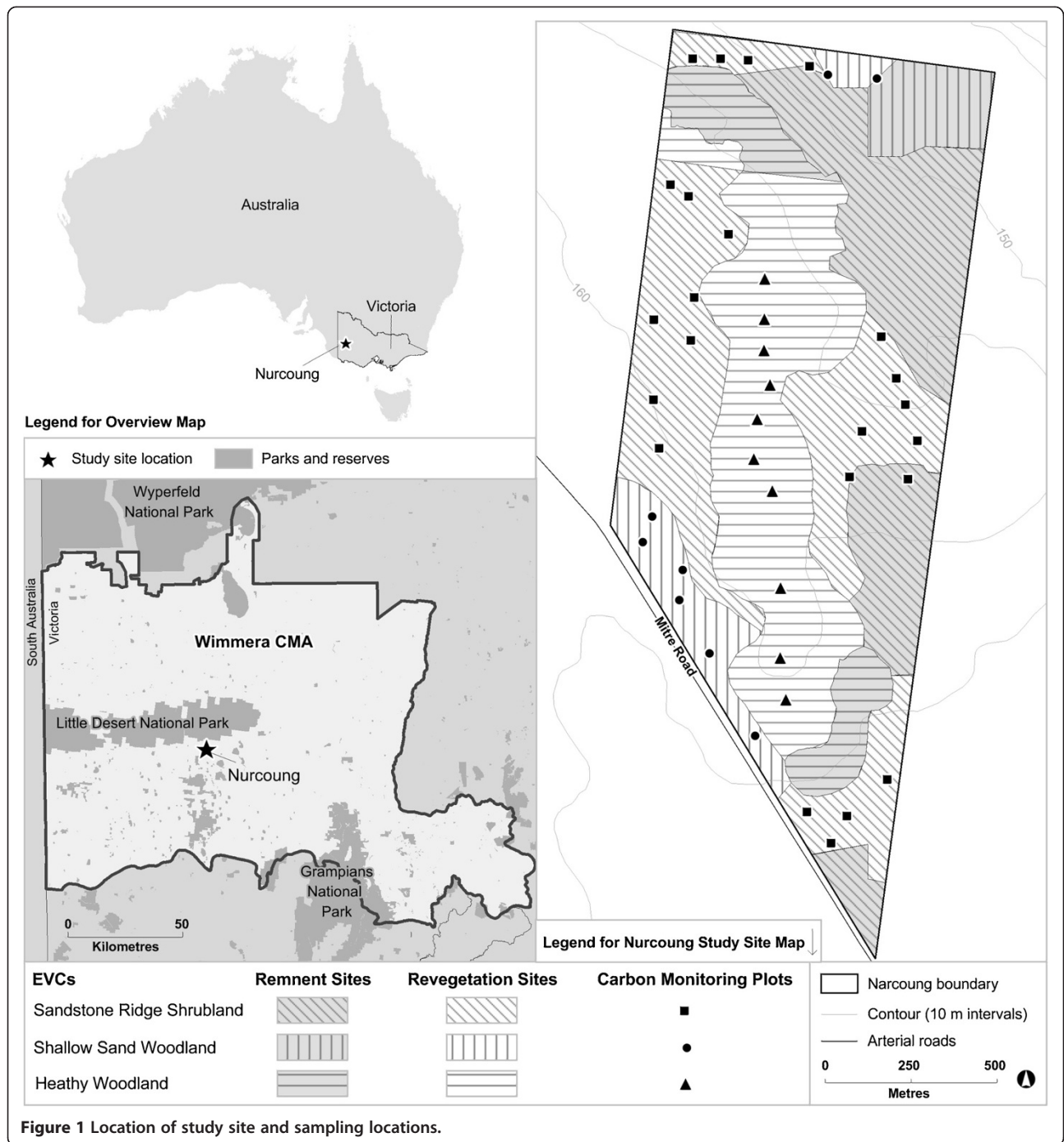


Figure 1 Location of study site and sampling locations.

the restoration. In 2008, the Nurcoung property was purchased by *Greening Australia* under the auspices of their landscape scale vision *Habitat 141*, for the purpose of restoring native vegetation.

Restoration of native biodiversity would serve to enhance local biodiversity, increase connectivity between isolated patches of remnant vegetation, and to generate carbon credits to economically support further restoration activities. The restoration areas on the property

were classified under the Department of Sustainability and Environment's Pre-European Ecological Vegetation Classes (EVCs) (Biodiversity Interactive Map – 3.2 (2007) as Sandstone Ridge Shrubland (66 ha), Shallow Sands Woodland (12 ha), and Heathy Woodland (52 ha). The accuracy and validity of the EVC classification was assessed through on-site assessments of the soil and observations of plant species found in nearby remnants. This classification was then used to inform the choice of

restoration species mix and appropriate site preparation for each of the vegetation classes.

Site preparation

The presence of a variety of undesirable plants and small grazing mammals (rabbits) required the implementation of measures to reduce weedy competition, grazing, and browsing damage. More than 300 rabbit warrens were mapped between March and April of 2009, and were subsequently ripped using an excavator fitted with a ripping tine. In early July 2009, all mapped warrens were revisited and Phostoxin applied to those that had been reopened.

Exotic plant species typically included *Ehrharta calycina* (African Veldt grass), *Rumex* sp. (Sorrel), *Arctotheca calendula* (Capeweed), and *Erodium* sp. (Storksbill). These were treated with successive broad scale herbicide applications of Roundup Powermax 1.5 L/ha, Amitrole T 1.5 L/ha, Glean 7.5 g/ha, and Eject (Oust) 7.5 g/ha with 100 L water per ha using a tractor-mounted boom-sprayer. On the deeper sands associated with the Heathy Woodlands, 1 m-wide strips were cleared with the boom-sprayer. In addition, Cutlass 500 120 mL/ha, Metsulfuron 7 g/ha, ammonium sulphate 4 kg/1,000 L, Wetspray 200 mL/100 L, and water 70 L/ha were applied in order to control the soil-borne pests *Halotydeus destructor* (Red-legged earth mites) and *Agrotis* spp. (Cut worm). In areas supporting more than 50% indigenous ground cover, herbicide was only applied using a spot-spraying approach – clearing 1 m² of vegetation at least 6 m apart.

Seed collection and early-stage plant establishment

Seeds were collected from nearby sources such as adjoining private properties, roadside reserves, and the Nurcoung Flora and Fauna Reserve. For each species, at least 100 parent plants were selected as seed sources, with the exception of *Exocarpus cupressiformis* and *Acacia bivenosa*, which are rare in the surrounding area with only 30 parent plants identified. Seed-containing capsules were air dried and extracted by sieving. Cleaned seeds were stored in labelled polystyrene containers

within a sealed shipping container. Hard coated seeds were scarified prior to seeding.

Direct seeding was undertaken in June 2009 using a Rodden Seeder® at a rate of 250 g/km and inter-row spaces of 4 m. The spot-sprayed areas were seeded manually in July 2009. Large-seeded species (*Acacia* spp.) were scratched in to a depth of approx. 5–7 mm using a rake, while smaller seeded species were broadcast by hand. During July 2009, teams of 4–6 contractors planted prepared seedlings using pottiputki planters. Seedlings were selected randomly from hyco trays containing a mix of species prepared in the nursery. Rainfall (mm) measurements in the 6 months preceding the seeding and in the subsequent years are given in Table 1. Details of the species established in the various EVCs and their method of planting are provided in Table 2 and Figure 1.

Sampling design, data collection, and analysis

Permanent sample plots (12 × 20 m) were randomly established in July 2010 in each of the restoration areas, with 9, 10, and 24 plots demarcated in Shallow Sands Woodland (SSW), Heathy Woodland (HW), and Sandstone Ridge Woodlands (SRW), respectively. Individual plots were prepared to include three seeded rows. Plots were assessed for seedling recruitment and survival in May 2010, April 2011, and May 2012. Records of individual seedling development included their height and cover, and their location within the plot. These locations were used to facilitate the identification of new recruitment in subsequent evaluations. In October 2010, November 2011, and November 2012, a survey of all naturally occurring vegetation between rows within the permanent plots was conducted and classified using the Braun-Blanquet dominance score.

The composition of the species and selected soil cover parameters were analysed using a permutational MANOVA as recommended by Anderson (2001) and Quinn and Keough (2002) [using adonis (vegan 2.04 in R2.15)] (R Development Core Team 2012). Two underlying approaches were used here: i) year was considered as a

Table 1 Climatic condition associated with restoration: rainfall (mm) in the 6 months preceding the seeding of different ecological vegetation classes and in the subsequent years

Year	Mean annual rainfall (mm)	2009 Total rainfall		Mean annual temp (°C)	2009 Mean temperature (°C)	
		May – July	Aug – Oct		May – July	Aug – Oct
2008	330.08	132.5	118.6	21.9		
2009	411.60	147.6	129.8	22.9	15.2	18.5
2010	585.00			21.5		
2011	542.20			21.8		
2012	324.80			21.7		

Data for the rainfall and temperature was obtained from Natimuk and Horsham-Polkemet road weather stations, respectively, through the Australian Bureau of Meteorology.

Table 2 Details of the species established in the various ecological vegetation classes and their method of re-introduction

Species	Life form	Ecological vegetation class								
		SSW (12 ha)			SRW (66 ha)			HW (52 ha)		
		Method	No.	Kg	Method	No.	Kg	Method	No.	Kg
<i>Acacia bivenosa</i>	Small shrub	DS		0.15	DS		0.95			
<i>A. brachybotra</i>	Med shrub	DS		0.3	DS		3.2	DS		1.5
<i>A. calamifolia</i>	Med shrub	DS		1.7				DS		9
<i>A. glandulicarpa</i>	Small shrub	DS		0.1						
<i>A. paradoxa</i>	Med shrub							DS		0.5
<i>A. pycnantha</i>	Med shrub				DS		17.5	DS		5.3
<i>A. rigens</i>	Small shrub				DS		4	DS		1
<i>A. rupicola</i>	Small shrub	DS		0.1	DS		0.7			
<i>A. simmonsii</i>	Med shrub				DS		1.8	DS		0.9
<i>A. spiniscens</i>	Small shrub				DS		0.3	DS		0.2
<i>A. acinacea</i>	Med shrub	DS		0.3			3.2	DS		1.5
<i>Allocasuarina luehmannii</i>	Canopy tree	P/DS	720	0.8						
<i>A. muelleriana</i>	Small tree	P/DS	240	0.2	P	2310				
<i>A. verticillata</i>	Small tree	P/DS	480	0.8						
<i>Banksia marginata</i>	Small tree				P	990			520	
<i>Baeckea behrii</i>	Med shrub							DS		1
<i>Banksia ornata</i>	Small tree	P	120					P	2080	
<i>Callistemon rugulosus</i>	Med shrub	DS		0.3						
<i>Callitris gracilis</i>	Canopy tree	P/DS	1200	0.6						
<i>Callitris rhomboidea</i>	Canopy tree	P/DS	240	0.6	DS		3.4	P/DS	3900	1.5
<i>Calytrix tetragona</i>	Small shrub	DS		0.1				DS	1040	0.3
<i>Casuarina muelleriana</i>	Small tree				DS		1.3			
<i>Daviesia brevifolia</i>	Small shrub							DS		0.2
<i>Daviesia pectinata</i>	Small shrub	DS		0.2						
<i>Dodonaea viscosa</i>	Med shrub	DS		0.5				DS		2.8
<i>Eucalyptus araceae</i>	Canopy tree							DS		0.8
<i>E. araceae/baxterii</i>	Canopy tree							P	13000	
<i>E. behriana</i>	Canopy tree				P/DS	660	0.35			
<i>E. dumosa</i>	Canopy tree				P/DS	5940	1			
<i>E. froggattii</i>	Canopy tree				P/DS	1320	0.2			
<i>E. goniocalyx</i>	Canopy tree				P/DS	1320	0.5			
<i>E. incrassata</i>	Canopy tree				P/DS	2640	0.5			
<i>E. leptophylla</i>	Canopy tree				P/DS	2310	0.4			
<i>E. leucoxylon</i>	Canopy tree	P/DS	1800	0.5	P/DS	1320	0.6			
<i>E. viridis</i>	Canopy tree				P/DS	2640	0.25			
<i>E. viridis sp. wimmerensis</i>	Canopy tree				P/DS	2640	0.25			
<i>Exocarpus</i>	Med shrub	DS		0.06				DS		0.22
<i>Exocarpus</i>	Med shrub	DS		0.3				DS		0.6
<i>Glischrocaryon behrii</i>	Herb							DS		0.1
<i>Hakea muelleriana</i>	Med shrub	P	120					P	780	
<i>Lasiopetalum baueri</i>	Small shrub	DS		0.03	DS		0.35	DS		0.12
<i>Leptospermum continentale</i>	Med shrub							P/DS	520	0.3

Table 2 Details of the species established in the various ecological vegetation classes and their method of re-introduction (Continued)

<i>Leptospermum myrsinoides</i>	Med shrub	P/DS	120	0.4			P/DS	1300	0.5	
<i>Melaleuca lanceolata</i>	Med shrub				P/DS	1650	0.7	P/DS	1560	0.2
<i>M. uncinata</i>	Med shrub				P/DS	9900	0.3	P/DS	780	0.2
<i>M. willsoni</i>	Med shrub				P/DS	660	0.06	P/DS	520	0.04
<i>Xanthorrhoea australis</i>	Medium size							DS		0.5
Total			5,040	8.04		36,300	41.81		26,000	29.28

SSW, Shallow Sands Woodlands; SRW, Sandstone Ridge Woodlands; HW, Heathy Woodland, P, Species planted; DS, Species Direct seeded.

continuous variable to determine the effect of age on the composition of the vegetation, and ii) year was considered as a categorical variable to account for annual variations in environmental conditions (rainfall distribution, solar radiation, evaporation, and others) as well as the age of the vegetation. The composition of the vegetation was analysed further using the similarity percent (SIMPER) (vegan 2.04 in R2.15) to identify those factors or species that contributed most to the differentiation of the EVCs and the yearly effect.

These approaches were applied to three subsets of the data; the first subset comprised all plants identified in the plots, as well as the soil cover parameters as surrogate species. The PERMANOVA separated the EVCs on the basis of species composition as well as soil cover. The second dataset included only the plants assessed within each of the EVCs while the final data considered only the soil cover parameters.

Results

Year as categorical parameter

Species and soil cover parameters

The model presented in Table 3 shows that all factors, as well as interactions between year and the EVCs, significantly affect the composition of plants and soil surface, when considered in concert. The interaction between year and EVC shows that the species and soil cover parameters develop in different ways in the different plots and EVCs. The differences in composition also

Table 3 Results of the permutational MANOVA, analysing plants and soil surface composition and using the year of observation as a categorical variable

	Df	SS	MS	F-Model	R2	Pr (>F)
Year	2	6.908	3.454	48.473	0.210	0.001
EVC	2	3.948	1.974	27.704	0.120	0.001
Plot	40	12.184	0.305	4.274	0.370	0.001
Year × EVC	4	1.423	0.356	4.992	0.043	0.001
Year × Plot	72	8.23	0.114	1.604	0.250	0.025
Residuals	3	0.214	0.071		0.010	
Total	123	32.906			1.000	

R² = 0.993.

vary between plots and may indicate that the processes that govern vegetation and soil cover parameters differ at different spatial scales.

Soil cover parameters only

Table 4 shows significant effects of EVC, Year, and Plot on the composition of the soil cover parameters when they are considered separately. As above, there is a significant interaction between EVC and Year, as well as between Year and Plot. Soil cover parameters may therefore be considered to react differently to annual variations in environmental conditions, within the different EVCs and in the different plots. The SIMPER analysis of this data (Table 5) shows that most of the variation over the years is attributable to differences in the amount of bare soil recorded, rather than the leaf-litter cover.

Species composition only

Differences in plant composition were significantly affected by EVC but also by year of observation and the plots, only the interaction between Year × EVC was significant (Table 6). Therefore, as above, yearly changes in the composition differ between the EVCs.

Year as a continuous variable

Species and soil cover parameters

Using Year as a continuous variable considers the effect of time on the composition of the communities. In considering plants and soil parameters together, we note

Table 4 Results of the permutational MANOVA, analysing soil cover parameters, using the year of observation as categorical variable

	Df	SS	MS	F-Model	R2	Pr (>F)
Year	2	7.852	3.926	211.989	0.367	0.001
EVC	2	2.680	1.342	72.467	0.125	0.001
Plot	40	5.153	0.129	6.956	0.240	0.008
Year × EVC	4	0.547	0.137	7.386	0.026	0.004
Year × Plot	72	5.113	0.071	3.835	0.237	0.011
Residuals	3	0.056	0.019		0.003	
Total	123	21.404			1.000	

R² = 0.997.

Table 5 SIMPER analysis of soil parameters against year of observation

Years 2010 to 2011	contr	sd	ratio	av.a	av.b	Cumulative
Bare ground	0.232	0.194	1.197	10.610	23.519	0.365
Soil crusts	0.198	0.105	1.890	0.938	14.500	0.676
Moss	0.096	0.088	1.086	1.125	7.138	0.827
Lichen	0.083	0.058	1.433	0	5.357	0.957
Leaf litter	0.027	0.040	0.680	2.500	1.548	1.000
Years 2010 to 2012	contr	sd	ratio	av.a	av.b	Cumulative
Bare ground	0.283	0.227	1.243	10.610	22.938	0.485
Moss	0.138	0.146	0.948	1.125	9.583	0.722
Leaf litter	0.117	0.084	1.398	2.500	7.441	0.923
Soil crusts	0.037	0.080	0.460	0.938	1.369	0.986
Lichen	0.008	0.039	0.215	0	0.357	1.000
Years 2011 to 2012	contr	sd	ratio	av.a	av.b	Cumulative
Bare ground	0.219	0.180	1.217	23.519	22.938	0.362
Soil crusts	0.149	0.093	1.590	14.500	1.369	0.607
Moss	0.101	0.105	0.964	7.138	9.583	0.773
Leaf litter	0.077	0.052	1.476	1.548	7.441	0.900
Lichen	0.060	0.046	1.311	5.357	0.357	1.000

similar results (Table 7) to those reported above (Tables 3, 4, and 6). The interaction between Year and EVC also notes that changes in composition differ between EVCs over time. While time plays a significant role, the coefficient of determination (R^2) is somewhat lower than previously noted. Year as a categorical variable, therefore, seems to capture additional important environmental influences other than actual ageing of the vegetation. Such influences may include rainfall parameters, evaporation and solar radiation, and previous land uses. Somewhat surprisingly, the interaction between Year and Plot is not significant.

Soil cover parameters only

In considering the soil parameters (Table 8) we note that these are affected only by the Year and EVC – the interactions between Year and EVC, and between Year and

Plot are not significant. In addition, the coefficient of determination dropped from 0.997 to 0.689. This decline implies that important factors affecting soil surface composition are not included in the model. As we indicated above, this may be due to the more dynamic nature of the litter cover which may be masking longer-term changes. The lack of interaction between Year and EVC suggests that the soil parameters develop in a comparable way within the vegetation communities over time.

Species composition only

When the effect of time on the plant communities is considered, an interaction between Year and EVC is evident (Table 9). This should be expected, as the EVCs are likely to differ in their response to revegetation activities over time – primarily as a result of different species compositions used in the revegetation, soil conditions,

Table 6 Results of the permutational MANOVA, analysing plant composition and using the year of observation as categorical variable

	Df	SS	MS	F-Model	R2	Pr (>F)
Year	2	6.419	3.210	34.265	0.176	0.001
EVC	2	4.322	2.161	23.069	0.119	0.001
Plot	40	14.137	0.353	3.773	0.388	0.001
Year × EVC	4	1.833	0.458	4.892	0.050	0.001
Year × Plot	72	9.432	0.131	1.399	0.259	0.095
Residuals	3	0.281	0.094		0.008	
Total	123	36.423			1.000	

$R^2 = 0.992$.

Table 7 Results of the permutational MANOVA, analysing plants and soil surface composition and using the year of observation as continuous variable

	Df	F-Model	R2	Pr (>F)
Year	1	30.983	0.129	0.001
EVC	2	14.438	0.121	0.001
Plot	40	2.234	0.373	0.001
Year × EVC	2	3.758	0.031	0.001
Year × Plot	39	1.120	0.182	0.094
Residuals	39		0.163	
Total	123		1.000	

$R^2 = 0.837$.

Table 8 Results of the permutational MANOVA, analysing soil surface composition and using the year of observation as a continuous variable

	Df	F-Model	R2	Pr (>F)
Year	1	18.136	0.145	0.001
EVC	2	7.995	0.127	0.001
Plot	40	0.770	0.245	0.956
Year × EVC	2	1.324	0.021	0.264
Year × Plot	39	0.484	0.151	1.000
Residuals	39		0.311	
Total	123		1.000	

R² = 0.689.

and similar factors. The SIMPER analysis (Tables 10, 11, and 12) shows that *Ehrharta calycina*, *Erodium cicutarium*, and *Eragrostis elongata* account for most of the variation over the years.

Plant establishment strategies

Direct seeding

A total of 21, 27, and 26 species were direct-seeded in SSW, HW, and SRW, respectively. Of those, 6 (*Acacia glandulicarpa*, *Calytrix tetragona*, *Daviesia pectinata*, *Exocarpus* sp. 1 and *Exocarpus* sp. 2, and *Lasiopetalum baueri*) and 8 (*Baeckea behrii*, *Daviesia brevifolia*, *Exocarpus* sp. 1 and *Exocarpus* sp. 2, *Glischrocaryon behrii*, *Hakea muelleriana*, *Lasiopetalum baueri*, and *Xanthorrhoea australis*) species from SSW, and only one species (*Eucalyptus viridis* sp. *wimmerensis*) from HW did not show evidence of recruitment during the three sampling periods (Figure 2a).

During the 2010 assessment, we recorded 78, 455, and 506 seedlings that were recruited in the directly-seeded plots in the SSW, HW, and SRW, respectively. In the subsequent years' (2011 and 2012) assessments, seedling numbers had increased in all sampling locations (Figure 2a). Compared to SSW (287), large numbers of seedlings were recorded in HW and SRW EVCs. A total

Table 9 Results of the permutational MANOVA, analysing plants composition and using the year of observation as continuous variable

	Df	F-Model	R2	Pr (>F)
Year	1	31.751	0.122	0.001
EVC	2	15.434	0.119	0.001
Plot	40	2.534	0.391	0.001
Year × EVC	2	4.462	0.034	0.001
Year × Plot	39	1.214	0.183	0.014
Residuals	39		0.150	
Total	123		1.000	

R² = 0.850.

of 1,472 and 1,794 seedlings were recorded in HR and SRW EVCs, respectively (Figure 2b).

Planted seedlings

A total of 7, 11, and 13 species were planted in SSW, HW, and SRW, respectively. Of these, *Callitris gracilis* and *Callitris rhomboidea* from SSW and *Hakea muelleriana* and *Melaleuca lanceolata* from HW did not survive during the subsequent years. Survival rates of the hand-planted seedlings in the SRW were high when compared to the SSW and HW EVCs (Figure 3). In the SRW, 41% of seedlings were dominated by *Melaleuca uncinata*. Similarly, 62% and 59% of seedlings were dominated by *Eucalyptus leucoxylon* and *Eucalyptus araceae/baxterii*, respectively (Figure 3).

Discussion

Our study examined the development of restored sites with particular emphasis on seedling recruitment and the development of soil cover as potential indicators of long-term site stability and self-sustainability. These latter criteria underpin key aspects of successful restoration and are therefore important, and as such they should dictate the likelihood and requirement of allocating further rehabilitation inputs and efforts.

Our overall findings show that parameters that describe restored sites, including the recruitment of seeds, survival of planted seedlings, and interaction between EVC and soil cover parameters, develop in different ways within different EVCs and at different spatial scales. This may, in part, be attributable to the differences in species composition and regeneration density used in restoration projects for the different EVCs, which represents a reality of large-scale restoration projects such as this. In addition, the different vegetation classes are likely to respond differently to those environmental parameters that gave rise to the original differentiation of the vegetation types. Measures of restoration success, such as species recruitment, therefore need to be considered within this context (Monie et al., 2013).

The variation of the parameters we measured was also evident within a vegetation type. When developing monitoring systems, local scale differences in parameters will therefore need to be accounted for. Similarly, the temporal variation in measured parameters may mask underlying trends. For instance, a slow species-specific recruitment might be erroneously interpreted as a lack of restoration success, while a dynamic litter layer may mask the development of other important soil cover parameters or processes.

Direct seeding and planted seedling

In view of the short study period and despite our best efforts, the value of a statistical analysis of the seedling data is possibly ambiguous. Results show an overall

Table 10 SIMPER comparison of plant composition 2010 to 2011

Years	contr	sd	ratio	av.a	av.b	Cumulative
<i>Ehrharta calycina</i> *	0.061	0.079	0.776	6.673	14.188	0.074
<i>Erodium cicutarium</i> *	0.056	0.041	1.357	5.548	17.586	0.141
<i>Eragrostis elongate</i>	0.053	0.048	1.092	15.085	11.236	0.205
<i>Arctotheca</i> sp.*	0.049	0.038	1.290	14.350	0.714	0.264
<i>Taraxacum</i> sp.1*	0.041	0.039	1.055	0.063	11.995	0.314
<i>Lolium perenne</i> *	0.040	0.056	0.718	3.615	10.879	0.362
<i>Rytidosperma caespitosa</i>	0.034	0.046	0.746	5.178	7.590	0.403
<i>Acetosella vulgaris</i> *	0.034	0.036	0.941	0.188	10.333	0.445
<i>Trifolium arvense</i> *	0.032	0.033	0.952	2.558	9.271	0.483
<i>Chloris truncata</i>	0.031	0.040	0.788	0.563	9.262	0.521
<i>Vulpia</i> sp.*	0.024	0.027	0.909	3.125	7.490	0.550
<i>Rytidosperma setacea</i>	0.024	0.040	0.596	1.495	6.290	0.579
<i>Drosera spatulata</i>	0.020	0.037	0.541	5.178	0.060	0.603
<i>Trifolium subterraneum</i> *	0.017	0.028	0.627	4.490	1.786	0.624
<i>Vittadinia cuneata</i>	0.017	0.022	0.775	4.063	2.674	0.645
<i>Romulea</i> sp.*	0.017	0.018	0.943	2.438	4.167	0.665
<i>Trifolium</i> sp.*	0.017	0.029	0.569	4.490	0.774	0.685
<i>Hypochaeris glabra</i> *	0.015	0.016	0.898	4.188	0.417	0.703
<i>Rytidosperma auriculata</i>	0.013	0.023	0.588	1.063	3.210	0.719
<i>Eragrostis brownii</i>	0.013	0.034	0.373	0.000	3.750	0.735
<i>Juncus pauciflorus</i>	0.013	0.020	0.655	3.495	1.131	0.750

*, Exotic species.

increase in established seedlings at the sites. However, some of the species broadcast in these three EVCs did not show evidence of recruitment during the sampling period. Whilst these species may have germinated but failed to establish during subsequent months, without post-seeding monitoring data it is difficult to identify the actual reasons. This is an important consideration because seedling recruitment is a vital component if restoration efforts are to achieve a self-sustaining ecosystem (SER, 2002).

Although these restored areas were utilised for cropping and sheep grazing for the past 50 years, most of the species broadcast or hand planted as part of the restoration efforts survived during the subsequent years. Apparently, the area provided a receptive seedbed and there were suitable conditions for these species to recruit and survive in subsequent years. It is also anticipated that these seedlings may provide additional seed source and provide suitable conditions for further recruitments of native species at a later stage. The three EVCs under study may thus have potential to develop structure and complexity.

Soil cover parameters

In comparing the coefficient of determination with Year as a categorical variable as opposed to Year as a measure of time, we anticipate considerable annual changes in

the composition of both species and soil cover parameters that are not attributable to age. Important to note is the interaction between Year of observation (as categorical variable) and Plot. It is therefore necessary to anticipate variation in the response of different parts of a site to a particular restoration effort. When we consider such parameters as indicators of restoration success, we must note that parameters will also respond to annual differences in local environmental conditions. We consider, for instance, that the amount of litter cover is substantially more dynamic than the amount of bare ground, soil crusts, mosses, and lichens, since it is subject to redistribution by wind. This movement of the litter subsequently results in an increased variability in the amount of bare ground exposed, and other soil cover parameters. While litter cover is of ecological importance in creating micro-habitats that may support seedling establishment, it is an unsuitable indicator of vegetation recovery under young stands. However, the indicator should be monitored in future as it may be more reliable when the vegetation becomes denser and its redistribution by wind becomes less of a factor.

Plant composition

Despite our arguments above, we cannot discount the effects of time since restoration depends on the

Table 11 SIMPER comparison of plant composition 2010 to 2012

Years	contr	sd	ratio	av.a	av.b	Cumulative
<i>Erodium cicutarium</i> *	0.078	0.061	1.266	5.548	26.088	0.093
<i>Ehrharta calycina</i> *	0.062	0.085	0.732	6.673	14.148	0.167
<i>Eragrostis elongata</i>	0.058	0.055	1.072	15.085	12.293	0.236
<i>Arctotheca</i> sp.*	0.047	0.039	1.199	14.350	1.429	0.292
<i>Vulpia</i> sp.*	0.044	0.053	0.831	3.125	14.029	0.345
<i>Rytidosperma caespitosa</i>	0.033	0.050	0.650	5.178	6.414	0.383
<i>Lolium perenne</i> *	0.032	0.042	0.752	3.615	8.552	0.421
<i>Taraxacum</i> sp.1*	0.025	0.017	1.504	0.063	7.440	0.452
<i>Chloris truncata</i>	0.025	0.037	0.674	0.563	7.069	0.482
<i>Acetosella vulgaris</i> *	0.025	0.037	0.665	0.188	7.714	0.511
<i>Austrodanthonia setacea</i>	0.024	0.049	0.493	1.495	5.943	0.540
<i>Trifolium arvense</i> *	0.022	0.027	0.816	2.558	5.710	0.567
<i>Bromus diandrus</i> *	0.022	0.048	0.447	0.188	7.317	0.593
<i>Drosera spatulata</i>	0.020	0.037	0.532	5.178	0.000	0.616
<i>Romulea</i> sp.*	0.019	0.022	0.868	2.438	4.940	0.639
<i>Vittadinia cuneata</i>	0.018	0.025	0.732	4.063	3.090	0.661
<i>Hypochaeris glabra</i> *	0.015	0.017	0.897	4.188	0.179	0.679
<i>Trifolium</i> sp.*	0.015	0.029	0.518	4.490	0.000	0.697
<i>Trifolium subterraneum</i> *	0.015	0.029	0.514	4.490	0.357	0.715
<i>Juncus pauciflorus</i>	0.014	0.020	0.691	3.495	1.488	0.731
<i>Eragrostis brownii</i>	0.013	0.033	0.398	0.000	4.167	0.747
<i>Austrostipa mollis</i>	0.012	0.021	0.581	1.375	2.555	0.761

*, Exotic species.

Table 12 SIMPER comparison of plant composition 2011 to 2012

Years	contr	sd	ratio	av.a	av.b	Cumulative
<i>Ehrharta calycina</i> *	0.065	0.075	0.875	14.188	14.148	0.093
<i>Erodium cicutarium</i> *	0.057	0.047	1.223	17.586	26.088	0.175
<i>Eragrostis elongata</i>	0.047	0.054	0.855	11.236	12.293	0.241
<i>Lolium perenne</i> *	0.040	0.050	0.810	10.879	8.552	0.298
<i>Vulpia</i> sp.*	0.039	0.045	0.878	7.490	14.029	0.354
<i>Rytidosperma caespitosa</i>	0.034	0.049	0.699	7.590	6.414	0.402
<i>Acetosella vulgaris</i> *	0.034	0.034	0.993	10.333	7.714	0.451
<i>Chloris truncata</i>	0.033	0.036	0.912	9.262	7.069	0.497
<i>Rytidosperma setacea</i>	0.030	0.044	0.669	6.290	5.943	0.540
<i>Taraxacum</i> sp.1*	0.027	0.029	0.923	11.995	7.440	0.578
<i>Trifolium arvense</i> *	0.024	0.027	0.899	9.271	5.710	0.613
<i>Bromus diandrus</i> *	0.020	0.042	0.471	0.952	7.317	0.641
<i>Eragrostis brownii</i>	0.019	0.037	0.509	3.750	4.167	0.668
<i>Romulea</i> sp.*	0.018	0.018	1.001	4.167	4.940	0.694
<i>Vittadinia cuneata</i>	0.015	0.027	0.554	2.674	3.090	0.715
<i>Oxalis pes-caprae</i> *	0.014	0.033	0.413	3.090	2.738	0.734
<i>Taraxacum</i> sp. 2*	0.012	0.017	0.708	3.805	1.131	0.752

*, Exotic species.

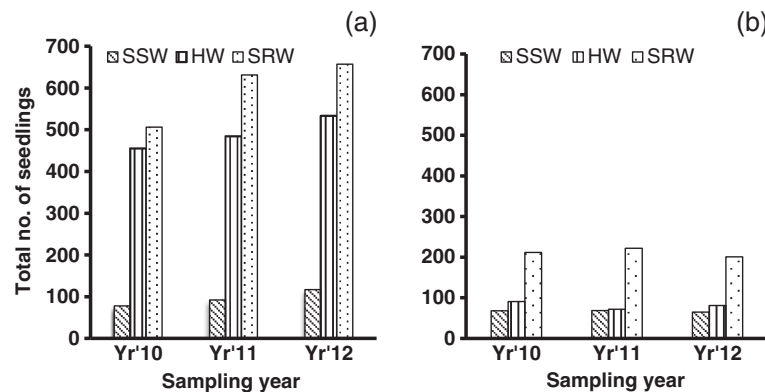


Figure 2 Total number of seedlings found as a result of direct seeding (a) and planted (b) in the three EVC.

development of vegetation conditions. The SIMPER analysis shows that herbaceous species, for the most part, cause most of the differences in vegetation composition. However, we would also like to emphasize that a significant proportion of the ground cover vegetation are exotic species. Further, the top six contributing ground cover species include the 2 or 3 natives, including *Austrodanthonia espitosa* and *Eragrostis elongata*, which are widespread across southern and eastern Australia in a wide range of ecosystems. This is not surprising, as such species are often quicker to respond to environmental factors such as rainfall. Monitoring of such species may therefore obscure short-term development, and we must therefore emphasize the need for selective monitoring of different vegetation components. Short-term stability may in part be deduced from the composition of the vegetation that responds more readily to annual

environmental variation. Longer-term results, in turn, are more likely to be reflected by those plants with longer development- and life-cycles.

Conclusions

A total of 47 species were involved in this restoration project, and all the seeds used in the regeneration were sourced from nearby adjoining private properties, roadside reserves, and the Nurcoung Flora and Fauna Reserve. This number, however, represents only a small percentage of species found in these remnant areas. Consequently, land that has been used for pasture and grazing, even with human intervention, will take a considerable time to recover. This may be attributable to significant changes in soil condition, depletion of the native soil stored seedbanks, continuous use of chemicals and pesticides, and continuous grazing by native and exotic grazers. Notwithstanding these pressures, one of the most promising results we noted from this study is that seeds and seedlings used to restore these areas have managed to germinate and survive during our period of observation. This is very encouraging, and we anticipate that in coming years, currently established seedlings and saplings may develop to provide suitable conditions for birds and other fauna to naturally introduce additional propagules (Bhullar and Majer, 2000; Majer et al., 2001). Thus far, the restored sites are developing along a trajectory we consider desirable, although it is too early to determine whether the restoration sites are in a 'natural' or 'novel' state. We therefore consider that continuous monitoring of these sites is essential to further understand the nature of the restoration trajectory (Seastedt et al., 2008).

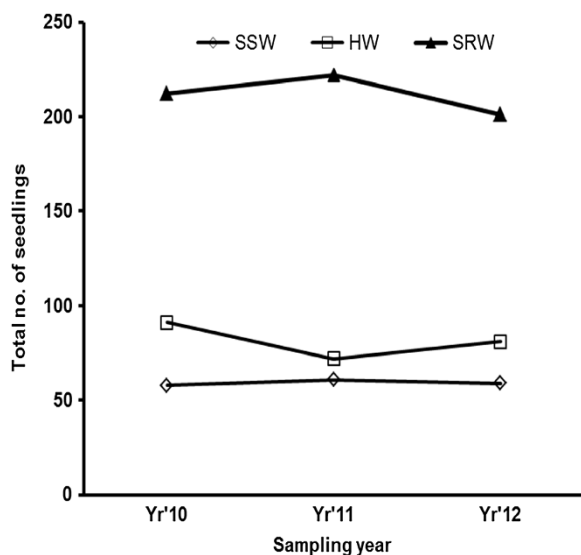


Figure 3 Survival pattern of planted seedling in the SSW, HW, and SRW ecological vegetation classes.

A final reflection: natural or novel?

Ecological restoration following any form of disturbance is dependent on whether the critical physical resources assembled during the rehabilitation process adequately

resemble the pre-disturbance conditions. A key theme of this special issue (relating to novel ecosystems in ecological restoration) is whether rehabilitated ecosystems bear sufficient semblance to natural, historic, and/or pre-disturbance systems, or whether these systems have formed stable alternative ecosystems leading to the formation of so called hybrid or novel systems (due to new and perhaps irreversible/reversible assemblies of abiotic and biotic components) (Perring et al., 2013).

Although the restoration project at Nurcoung is relatively new, results obtained from this study, to date, show that restoration efforts appear to be promising as evidenced by the significant number of planted seedlings and broadcast seeds that are established and surviving. As Audet et al. (2013) found, restored sites are travelling on a positive trajectory when the desired ecosystem characteristics are starting to establish there. Some of the desired ecosystem characteristics are now starting to establish in the restored Nurcoung sites. However, it will take a considerable amount of time for this to become a fully functioning ecosystem (Doley and Audet, 2013). It is only then that we would be able to determine whether it is a natural or novel system (Shackelford et al., 2013a; Shackelford et al., 2013b). As Monie et al. (2013) pointed out in their conclusion, seedling recruitment is one of the useful parameters in detecting development trends towards a sustainable restoration target, but it will be some time before we could determine any long-term resemblance to the pre-disturbance conditions. Restoring native biodiversity and ecosystem function among degraded landscapes is, of course, technically and financially demanding (Menz et al., 2013). Hence, it is necessary to assess ongoing ecological trajectories dispassionately and, when possible, using multiple indicators of ecosystem development and resilience. Ultimately, our findings support the convergence of rehabilitated sites toward reference communities. Then again, it should be recognized that, where sites may diverge from intended (or aspirational) targets, intervention should be required to achieve the highest ecological outcome, regardless of whether these are deemed natural, hybrid, or novel (Doley and Audet, 2013; Perring et al., 2013).

Abbreviations

ECV: Ecological vegetation classes; HW: Heathy woodland; SRW: Sandstone ridge woodlands; SSW: Shallow sands woodlands.

Competing interests

The authors declare that they have no competing interests with regard to any of the reported findings.

Authors' contributions

Several *Greening Australia* members have been involved in this project, and their names have been listed in the acknowledgements. JG was the major person involved in data gathering, in the field. SF and PG have analysed and interpreted the data, and have primarily drafted the manuscript. All authors have approved the final draft of this manuscript.

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