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Establishment of *Eucalyptus gomphocephala* (Tuart) woodland species in an abandoned limestone quarry: effects after 12 years

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Surface mining and quarrying profoundly affect landscapes and vegetation, so restoration of abandoned quarries attempts to create species-rich ecosystems for erosion control and fauna habitat. This study examined the success after 12 years of imported topsoil, sewage sludge, micronutrients, and fertiliser tablets applied at planting (all with and without broadcast fertiliser) on the survival, growth and health of six-month old seedlings of *Eucalyptus gomphocephala*, *Acacia saligna*, *Banksia prionotes*, *B. attenuata*, *E. decipiens*, *Templetonia retusa* and *Dodonaea aptera* in an abandoned limestone quarry in a mediterranean type climate in south-west Western Australia. Natural recruitment of seedlings of these species was also noted. After 12 years, overall survival was 17.4%, ranging from 42% in *E. gomphocephala* to 1% in *T. retusa*. Treatment combinations did not influence survival of any species, nor did growth (measured as height and DBHOB) vary in response to treatment. Treatment did not influence the health of any species significantly, with the exceptions of *E. decipiens* (healthiest in the All treatment) and *B. attenuata* (significantly lower levels of health when exposed to broadcast fertiliser). *A. saligna*, *D. aptera* and other local species from surrounding woodlands had naturally recruited seedlings. To date, although there is no evidence that any of the treatments tested is a panacea for success in re-establishing the study species in the medium-term, the study shows that vegetation native to the area can be re-established in abandoned limestone quarries at this site.

Key words: limestone quarries, restoration, seedling establishment, treatments, sewage sludge, fertiliser.

INTRODUCTION

Karst landscapes were exploited for hundreds of years in countries such as Lebanon (Khater *et al*. 2003), Spain (Sort and Alcaniz 1996; Moreno-Penaranda *et al*. 2004), Portugal (Clemente *et al*.

2004), South Africa (Hall *et al.* 2003), India (Rao and Tak 2002) and Australia (Ruthrof 1997). Limestone quarries represent the most conspicuous and, in process and landform terms, the most dramatic, anthropogenic impact on karst terrain (Gunn and Bailey 1993). Removal of the soil profile during limestone extraction produces a highly calcareous and alkaline substrate with little organic carbon or microbial activity; decreased soil fertility (reduced available N, P and some micronutrients) (Ruthrof 1997); decreased water infiltration and holding capacity; and increased risk of water and wind erosion (Russell and Isbell 1986). Low levels of nutrients and water can delay or prevent recolonisation (Sort and Alcaniz 1996; Clemente *et al.* 2004).

In Western Australia, although over 3 000 000 tonnes of limesand/ limestone are mined annually (worth over $23 million every year (DOIR 2005)), little work has been undertaken in developing restoration protocols for abandoned limestone quarries. Most documented attempts are from the United Kingdom (Dixon and Hambler 1984; Davis *et al.* 1985, 1993; Bailey and Gunn 1991) and, more recently, South Africa (Hall *et al.* 2003) and Portugal (Clemente *et al.* 2004). Natural recolonisation of limestone quarries by a few spcies occurs (Bailey and Gunn 1991; Riley *et al.* 2003; Davis 1979; Yuan *et al.* 2006), but unacceptably slowly (Bailey *et al.* 1991; Wheater and Cullen 1997; Cullen *et al*. 1998). Management to accelerate plant establishment must overcome a lack of propagules (see Koch *et al.* 1996; Bell 2000; Grant 2006; Koch 2007) and the hostile physical and chemical conditions of the substrate (Wheater and Cullen 1997; Clemente *et al.* 2004).

Treatments to ameliorate limiting factors in abandoned limestone quarries include sewage sludge, fertilisers (especially those rich in nitrogen and phosphorus) and adding topsoil. Sewage sludge is cheap and easily applied. Previous reports suggest it improves soil physical and chemical characteristics (O'Connor *et al.* 1986; Sopper 1993; Labrecque *et al.* 1995) while controlling erosion (Sort and Alcaniz 1996) and increasing plant biomass and cover (Moreno-Penaranda *et* *al.* 2004). However, the weed load is higher in the first year (Ruthrof 1997) and lower species richness of desirable plants may result (Moreno-Penaranda *et al.* 2004). Adding nutrients, particularly nitrogen and phosphorus, can improve plant growth (Dixon and Hambler 1984; Davis *et al.* 1985; Richardson and Evans 1986; Clemente *et al.* 2004; Yuan *et al.* 2006), but may facilitate the growth of a few dominant species (Davis *et al.* 1985) that out-compete others for water and nutrients (Clemente *et al.* 2004). Adding topsoil as a soil treatment, rather than as a seed source, improves organic matter content, microbial activity, nutrients and water infiltration (Munshower 1994; Riley *et al.* 2003). However, even topsoil collected adjacent to restoration sites may not establish similar vegetation (Hall *et al.* 2003). It is costly to purchase and transport (Bailey *et al.* 1991) and may import plant diseases or weeds. Whatever treatments are chosen, long-term monitoring is required to determine the relative success of different species and the effects of any treatments, taking into account cost and effort. On-going monitoring indicates whether re-treatment or in-fill plantings are required.

In Western Australia, Ruthrof (1997) established that adding a complete fertiliser in slow release pellet form was the most successful amendment with regards to growth and survival compared to sewage, micronutrients, topsoil and broadcast fertiliser. To determine if effects persisted in the medium-term, we revisited Ruthrof's (1997) study site to collect data on the survivorship, growth, health and natural recruitment of plant species after 12 years to answer these questions:

1) can local plant species be established in an abandoned limestone quarry over the medium-term?

2) after 12 years, are the survival, growth and health of local plant species influenced by the initial soil treatments: sewage sludge, topsoil, fertiliser tablets, micronutrients and broadcast fertiliser?

3) after 12 years, do local plant species show evidence of recruitment, and is this influenced by the soil treatments?

STUDY AREA AND METHODS

The study area

The study was conducted at Cockburn Cement Quarry 7, approximately 25 km south of Perth, Western Australia (32^{o}08’14.57”S, 115^{o}48’15.07”E) on the Spearwood Dune System of the Swan Coastal Plain. It consists of a core of aeolinite (Tamala Limestone) with a hard capping of secondary calcite, overlying varying thicknesses of yellow to brown sand (McArthur 1991). The surrounding area has been cleared of *Banksia–Eucalyptus–Allocasuarina* woodland for market gardening, floriculture and housing. The area has a mediterranean climate with hot, dry summers and cool, wet winters and an average annual rainfall of 840 mm at the closest meteorological station: 86% of rain falls between May and August (Jandakot Airport 32^{o}10’S, 115^{o}88’E). The mean maximum temperature for the hottest month (February) is 31.2^{o}C and the mean minimum temperature of the coldest months (July and August) is 7^{o}C (BOM, 2008).

Cockburn Cement’s goal for abandoned quarries is to control erosion and to create a vegetation community similar to that of the surrounding woodland. Given this goal, several restoration strategies have been developed, including covering the quarry floor with overburden/topsoil mixture, ripping, the introduction of local plant species, and rabbit-proof fencing**.**

Local plant species

Six local plant species from two life forms were chosen to represent the surrounding vegetation community: mid-canopy and upper canopy species (*Eucalyptus gomphocephala*, *Acacia saligna*, *Banksia prionotes*, *B. attenuata*, *E. decipiens)* and understorey species (*Templetonia retusa* and *Dodonaea aptera)*. *E. gomphocephala* and *A. saligna* survived in previous revegetation activities in Quarry 7, the other species had not (Ruthrof 1997). Plants were grown at a nursery for six months before planting in May 1995. Their survival was re-assessed after 12 years.

Experimental design

The research questions were addressed by two experiments set up within 20 metres of each other. The first explored the various treatments in a subtractive, split plot design (Table 1), the second one a simple All (Table 1) and unfertilised (Nil) treatments design.

[Table 1 here]

Experiment 1 was made up of four blocks, each containing six plots measuring 6 x 10 m. Treatments were randomly allocated to plots. The additional factor of broadcast fertiliser or no broadcast fertiliser was then added as a split-plot, each 5 x 6 m (Table 1, Figure 1). Treatments were applied in a subtractive design to determine the response if a treatment was not added (e.g., All treatments minus topsoil or All treatments minus fertiliser tablets). Five plants of each study species were planted in each split-plot.

[Fig. 1 here]

Experiment 2 was made up of four blocks, each of which comprised four plots of 5 x 6 m. Treatments were applied as All (sewage sludge, topsoil, fertiliser tablets and micronutrients, as shown in Table 1) or unfertilised (Nil) treatments. Broadcast fertiliser application was allocated to plots randomly (Table 1 and Figure 1). Five plants of each study species were planted in each plot.

Influence of treatments on survival, growth, health and recruitment

Plant height and diameter (DBHOB), and health were used to evaluate plant performance and treatment responses. Health was noted by allocating each plant a rating of 1 to 5: 1 - dead; 2 - high levels of stress; nutrient disorders or herbivory and unlikely to recover; 3 - moderate levels of stress, nutrient disorders or herbivory; 4 - low levels of stress, few signs of herbivory or nutrient disorders; and, 5 - healthy, with new growth, and no signs of stress, nutrient disorders or herbivory. The presence or absence of reproductive structures was also noted. Plant height measurements were taken using a tape measure or a clinometer for plants over 3 m tall. Measurements of DBHOB were taken with callipers or diameter tape. The presence, number, and species of naturally recruited seedlings were recorded for each plot.

Statistical analysis

The influence of the treatments (sewage sludge, topsoil, fertiliser tablets and micronutrients, i.e. "treatment") and added broadcast fertiliser ("B") on survivorship of each species was analysed for Experiment 1 and Experiment 2 using log-linear analyses. These use a model-fitting approach to determine the most economical combination of main effects and interactions that best describes the data. The significance of effects of interest in the model was tested by removing them from the model and noting changes in the fit of the model to the observed data. In both Experiment 1 and Experiment 2, we were interested in significant interactions between survival and the variables species, treatment and B. Interactions involving variables other than survival were irrelevant, so the three-way interaction between them was included in the final model to avoid obtaining an overall lack of fit that may be caused entirely by interactions between the design variables (Statsoft 1999).

Analyses of height and health were complicated by survival, because there were cells in the design where no plants of some species survived 12 years. Accordingly, the unique combinations of +/- B and treatment where plants survived were treated as levels of a single new variable, combined treatment, in a one-way MANOVA with dependent variables of height and health. The multivariate test statistic was Rao's R. Where Rao's R was significant, the univariate statistics for height and health were examined. If these were significant, LSD tests were used to determine which treatments differed significantly from each other.

RESULTS

Experiment 1

Survivorship

The fitted model for the log-linear analysis using factors of species, survivorship, treatment and B included the three-way interaction treatment x species x B, and the two-way interaction species x survival (χ^2_{45}= 47.62, p = 0.37). Species x survival was significant (χ^2_{5} = 237.17, p < 0.01), with the highest survival found in the two upper canopy species (*E. gomphocephala*, 45.6% and *E. decipiens*, 22.8%), and one understorey species (*D. aptera*, 24.4%). *T. retusa* had the lowest survival rate (1.1%) (Figure 2). Survival did not vary with treatments.

[Fig. 2 here]

Influence of treatments on growth and health

Following 12 years of growth, the canopy species in the study, *E. gomphocephala* and *E. decipiens*, were the tallest, followed by the mid-storey species *A. saligna* and *B. prionotes*. The tallest plants were *E. gomphocephala* (mean 4.2 m; max. 9.5 m). Several *E. decipiens* were also over 6 m.

There was a significant positive influence of the treatment All-OM without broadcast fertiliser on the health of *E. decipiens* (Rao's R $_{(20,\ 140)}$ = 1.67; P < 0.0449) (Table 2). Univariate analyses showed that health score was significantly different across treatments ($F_{(1,2)}$ = 2.405, p = 0.016). Post hoc LSD tests within health revealed three broad groupings (Table 2). The plants in the treatment All-Pellet -B were least healthy and plants in the treatment All-OM -B were the healthiest.

[Table 2 here]

Some of the study species had flowered and set seed within the 12 year period. Fruits were noted on the serotinous species in the trial: *E. gomphocephala*, *E. decipiens* and *B. prionotes*. Of these, *B. prionotes* and *E. decipiens* had the highest abundance of canopy stored fruit (42 and 9.7% of plants, respectively).

Influence of treatments on natural recruitment

There was no significant effect of treatment on the number of recruits (Table 2). However, after 12 years *A. saligna* (96), *D. aptera* (31) had recruited seedlings in Experiment 1 (1080m^2). *A. cyclops* (31), *Kennedia prostrata* (4), *Olearia axillaris* (3), *T. retusa* (3) and *Hardenbergia comptoniana* (1) also recruited within the site, although they had not been deliberately planted.

Experiment 2

Survivorship

For Experiment 2, the fitted model for the log-linear analysis using factors of species, survivorship, treatment and B included the three-way interaction (treatment x species x B) and the two-way interaction species x survival (χ^2_{45} = 47.67, p = 0.37). Species x survival was significant

($\chi_5^2 = 237.18$, $p < 0.01$), with *E. gomphocephala* having the highest survival (38%). No *B. attenuata* or *T. retusa* survived (Figure 3). Survival did not vary significantly with treatments.

[Fig. 3 here]

Influence of treatments on growth and health

Growth, in terms of height and DBHOB, also did not vary significantly with treatments (Table 3). However, the health of *B. attenuata* was significantly lower in the treatment Control + broadcast fertiliser (Rao $R_{(6, 20)} = 4.72$; $p< 0.0038$).

[Table 3 here]

Influence of treatments on natural recruitment

There were no treatment responses in recruited seedlings with 1.9 $\pm$ 0.5 (All treatment) compared with 1.7 $\pm$ 0.4 seedlings per quadrat (control). *A. saligna* (14) and *D. aptera* (8) had recruited seedlings in Experiment 2 following 12 years. Although not planted, *A. cyclops* recruited 8 seedlings.

DISCUSSION

Can local plant species be established in an abandoned limestone quarry over the medium-term?

Local species should be used in restoration projects (Khater *et al*. 2003; Clemente *et al*. 2004) because they are more adapted to the local environmental conditions (climate, pests, pathogens and diseases) and are used by local fauna. Although survival rates were variable, some plants from all species planted survived 12 years. This, coupled with the evidence of natural recruitment for *A. saligna*, *D. aptera* and other local species, indicates that vegetation can be re-established in abandoned limestone quarries in this region in at least the medium-term.

Did treatments influence survivorship after 12 years?

There were no significant associations between survivorship and treatment in either experiment, suggesting that none of the treatments increased survivorship up to 12 years. However, Hall *et al*. (2003) suggest a 50 year monitoring regime to determine whether particular restoration approaches are successful.

The study species *E. decipiens, E. gomphocephala* and *D. aptera* had survival rates of 42% and less over 12 years, similar to those following one year (Ruthrof 1997). They may follow a common pattern in which the first year is difficult and plants surviving it have a good chance of surviving. Density was not an issue, because the density of plants in the study plots was no higher than present in *E. gomphocephala* woodlands (Ruthrof *et al*. 2003). Further work is needed to determine whether in such a harsh environment lower plant densities will improve survival rates, or whether higher planting densities are needed to achieve adequate density of overstorey species.

T. retusa (1%), *A. saligna* (25%), and *B. prionotes* (11%) had low survival rates. *A. saligna* is short-lived and typically senesces after a decade, so the results probably reflect senescence and survival in the quarry environment. *T. retusa* occurs naturally on shallow Australian limestone soils (Marchant *et al*. 1987) and some natural recruits were noted in Experiment 2. It was the most susceptible of all the study species to rabbit browsing (Ruthrof 1997). *B. prionotes* may suffer from phosphorus toxicity (Lamont 1993), although the lack of a significant association involving treatment, species and survival does not support this conclusion.

Did treatments influence growth and health after 12 years?

The few effects of treatments on growth and health noted were subtle, species specific, mainly short-term and not supportive of a 'one size fits all' approach. Sewage sludge can improve water infiltration rates and soil structure (Sort and Alcaniz 1998). However, Moreno-Penaranda *et al* (2004) found that fewer species resulted. In addition, sewage sludge can encourage weeds (Ruthrof 1997). A change in competitive balance, including competition with weeds, may have prevented a positive response to the treatment in our study.

Adding topsoil is only advantageous if it contains a local seed source, has low purchase and transport costs, is disease free, and has beneficial characteristics. If it contains a high weed load, then seedling establishment and growth can be compromised (Ruthrof 1997). In this study, topsoil addition did not improve health and growth over 12 years, although plants were taller after one year (Ruthrof 1997) Thus, this treatment assists establishment and growth in the short-term only.

Fertiliser application can cause rapid increase in vegetation cover (Clemente *et al.* 2004). For example, the use of the same type of fertiliser pellet as used in this trial significantly increased the growth of *E. gomphocephala* seedlings in bushland restoration trials (Ruthrof 2001; 2005). The fertiliser pellet produced the highest survival and growth rates one year after planting (Ruthrof 1996, 1997). However, broadcast fertilisers should be used cautiously when restoring nutrient-sensitive Proteaceae (Shane *et al*. 2004). In this study, neither fertiliser treatment significantly increased survival or growth after 12 years. The nutrients probably reverted quickly to unavailable forms, they stimulated plant-to-plant competition for other resources, particularly water, or the nutrient acquisition adaptations of the planted species compensated for variations in nutrients.

Did treatments influence recruitment after 12 years?

Given that the long term aim for restoration is to produce self-sustaining plant communities, it was significant that most study species flowered and set fruit, and two planted species (*A. saligna* and *D. aptera*) had recruited seedlings within 12 years. Thus, these local plant species can naturally recruit into abandoned limestone quarries and are suitable for future restoration. For all species, further research should be undertaken to increase survivorship, especially in the early years. Furthermore, we only examined six endemic species, whereas the local flora comprises dozens.

Five species from elsewhere naturally recruited seedlings within the 12 year study period, so establishment of non-planted local plant species in abandoned limestone quarries is possible. The majority of these species are colonisers, have long-lived soil seed banks and hard seeds, and are resilient in the harsh quarry environment. In a study of the floristics of mined areas of the Jarrah (*E. marginata*) forest, Koch and Ward (1994) suggested that the response to a severe disturbance, such as mining, leads to a predominance of seeders, as seen in this study. The establishment of resprouters requires longer term management (Bellairs and Bell 1993).

Continued intermittent intervention

In highly degraded systems continued intervention may be required to achieve restoration goals (Grant 2006). It is not a matter of removing the degrading factors, applying treatments to ameliorate soil conditions, reintroducing local plant species and then assuming that the system will become self sustaining. For example, only one third of the study species naturally recruited seedlings (*A. saligna* and *D. aptera*), while the two canopy species *E. gomphocephala* and *E. decipiens*, and the mid-canopy species, *B. prionotes*, did not.. Previous work has shown that, for example, *E. gomphocephala* rarely recruits in interfire periods, but can mass recruit seedlings following fire (Ruthrof *et al.* 2002; Ruthrof 2003). Therefore, at some time in the growth and development of the limestone quarry plant community, some type of disturbance event, such as fire, may be required to facilitate recruitment of particular species. Thus, if the restoration objective is to establish a self-sustaining woodland ecosystem which enhances or maintains conservation values, then guidelines need to be established not only to outline the degree of intervention required (Yates *et al*. 2000), but also to outline strategies for continued management of restoration sites.

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Table 1. Description of treatments for Experiment 1 and Experiment 2

No.	**Treatment**	**Application rate**
1	Sewage sludge	77 t/ha (after Wong and Ho 1994)
2	Topsoil	5 cm depth
3	Fertiliser tablet	1 tablet per seedling. Total N as ammonium and urea form 20.0%, Total P as phosphate water soluble, citrate soluble and citrate insoluble 4.40%, K as sulphate 8.2%, Ca as phosphate 4.0%, S as sulphate 6.0%, Mg as oxide 0.2%, Cu as sulphate 0.03%, Zn as oxide 0.50%, Fe as sulphate 0.16%, Mn as sulphate 0.16%, Mo as molybdate 0.01% and B as tetraborate 0.01%
4	Micronutrients	Zn as ZnO kg/ha, Cu as $CuSO_4$ 10 kg/ha, Mn as $MnSO_4$ 25 kg/ha, Fe chelate Fe EDHHA 100 kg/ha, B as Borax 5 kg/ha
5	Broadcast fertiliser	Phosphate as 400 kg superphosphate /ha and K as 100 kg potassium chloride /ha (after Bolland and Baker 1990, at higher rate due to calcareous substrate)

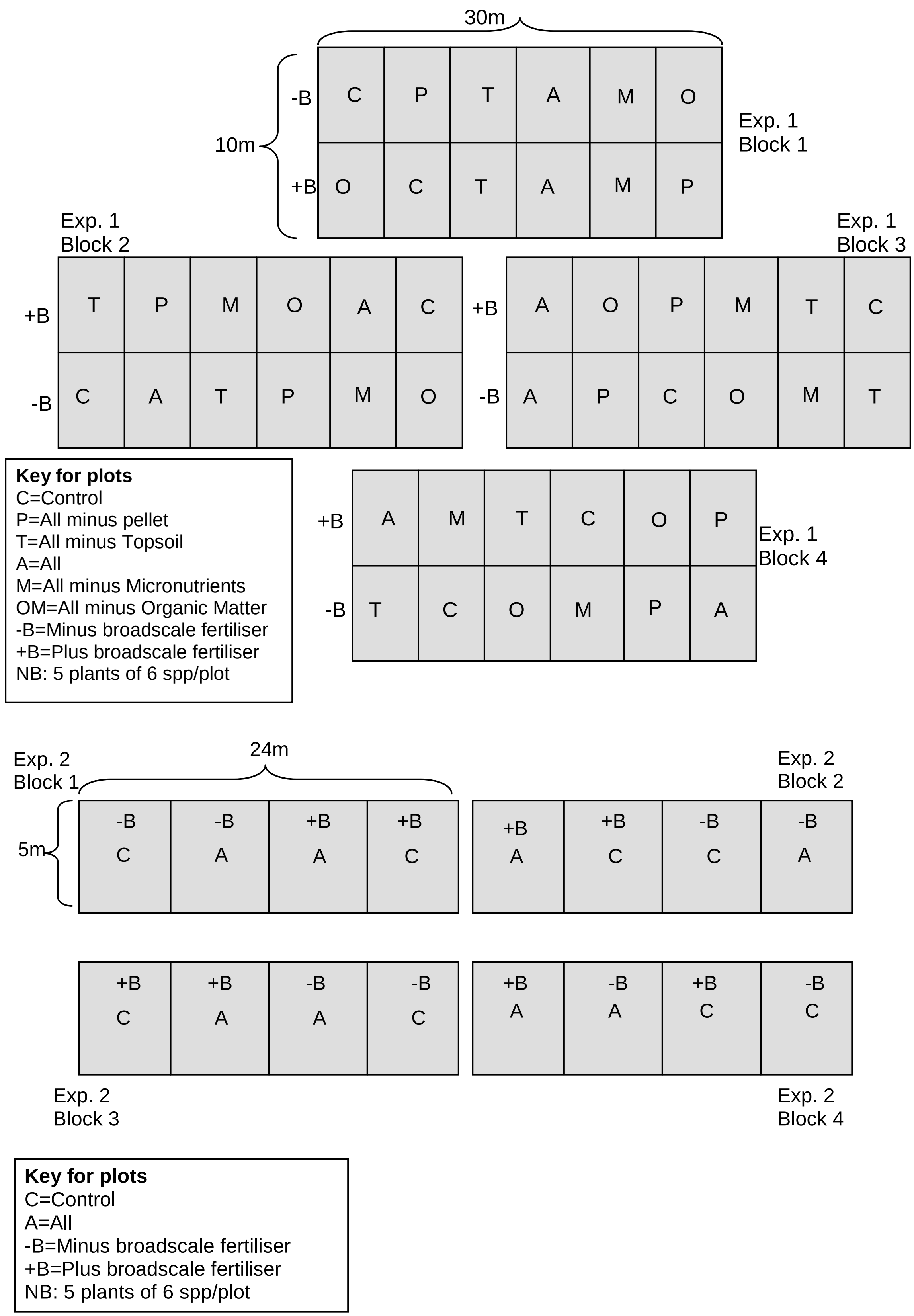

Fig. 1. Layout of Experiment 1 and Experiment 2

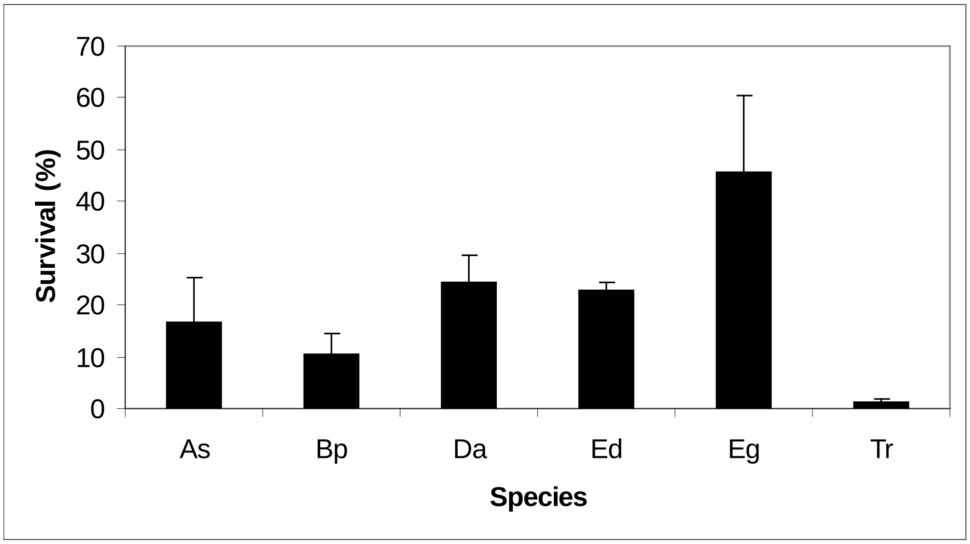

Fig. 2. Species survival in the limestone quarry restoration trial following 12 years of growth – Experiment 1. Species codes: As = *A. saligna*, Bp = *B. prionotes*, Da = *D. aptera*, Ed = *E. decipiens*, Eg = *E. gomphocephala*, Tr = *T. retusa*. Values are means of 180 plants. Vertical bars indicate standard errors.

Table 2. Responses of local plant species to site treatments in a limestone quarry, 12 years after planting – Experiment 1. Mean height (cm), mean DBHOB (cm), mean health (1-5, 1 signifying dead, 5 signifying healthy), and presence of recruitment (mean number of recruits). Treatment codes: Pellet = slow release fertiliser tablet, Micro = micronutrients, OM = Sewage sludge, B = Broadcast fertiliser. Species codes: Da = *D. aptera*, Ed = *E. decipiens*, Eg = *E. gomphocephala*. Survival rates of *A. saligna*, *B. prionotes* and *T. retusa* were too low to conduct analysis. Note that LSD, indicated with superscript letters beside the means, is shown only where significant differences occur.

Species	Treatments											
	Control		All-Pellet		All-Topsoil		All		All-Micro		All-OM	
	-B	+B	-B	+B	-B	+B	-B	+B	-B	+B	-B	+B
	Mean height (m) (S.E.)											
Da	0.8(0.3)	1.3(0.2)	0.8(0.2)	0.6(0.2)	1.5(0.1)	1.3(0.4)	0.7(0.2)	1.1(0.2)	1.2(0.2)	1.7(0.0)	0.7(0.1)	0.8(0.1
Ed	3.9(0.4)	1.3(0.0)	3.2(1.3)	6.7(0.9)	3.4(0.5)	0.6(0.0)	3.6(0.9)	3.7(1.3)	3.6(0.8)	1.8(0.0)	4.9(0.0)	5.2(0.9
Eg	3.4(0.7)	1.3(0.0)	1.8(0.8)	6.5(2.4)	5.6(1.7)	4.1(0.0)	4.2(0.4)	3.4(0.8)	7.0(1.3)	2.2(0.0)	4.4(0.0)	3.9(0.9
	Mean DBHOB (cm) (S.E.)											
Ed	4.6(1.4)	0.3(0.0)	7.9(2.1)	12.9(4.2)	2.9(1.0)	3.7(0.4)	5.0(2.1)	5.6(2.8)	3.6(1.5)	4.2(0.7)	5.9(0.0)	6.9(2.4
Eg	3.8(0.8)	2.0(0.0)	7.4(3.3)	6.9(1.2)	9.4(2.3)	11.1(3.9)	7.1(0.8)	3.6(0.8)	8.2(3.2)	6.6(3.2)	8.7(1.9)	7.8(1.2
	Mean health (1-5) (S.E.)											
Da	3.5(0.6)	4.5(0.5)	3.7(0.7)	5.0(0.0)	4.3(0.5)	4.0(0.4)	3.0(0.7)	3.7(0.3)	4.3(0.3)	5.0(0.0)	3.4(0.4)	3.8(0.3
Ed	4.7(0.3)bc	2.0(0.0)ab	4.0(0.7)a	5.0(0.0)ab	4.3(0.3)ab	4.0(0.0)abc	5.0(0.0)bc	4.0(0.7)bc	4.0(0.6)bc	2.0(0.0)ab	4.0(0.0)c	4.4(0.2
Eg	3.0(0.0)	2.0(0.0)	2.2(0.2)	3.3(0.3)	3.3(0.3)	3.0(0.0)	3.0(0.0)	3.3(0.4)	3.3(0.3)	2.0(0.0)	3.0(0.0)	3.0(0.0
	Mean number of recruits (S.E.)											
All	4.3(2.8)	0.7(0.7)	5.3(3.4)	6.3(2.2)	3.7(1.3)	0.7(0.7)	5.6(3.3)	3.3(0.9)	5.7(2.0)	2.3(1.2)	3.7(1.3)	5.0(4.0

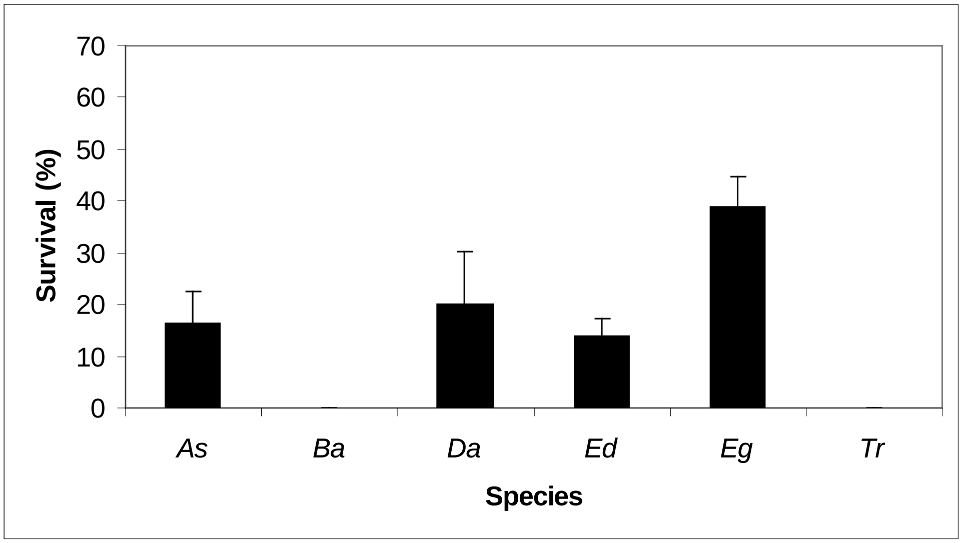

Fig. 3. Species survival in the limestone quarry restoration trial following 12 years of growth – Experiment 2. Species codes: As = *A. saligna*, Ba = *B. attenuata*, Da = *D. aptera*, Ed = *E. decipiens*, Eg = *E. gomphocephala*, Tr = *T. retusa*. Values are means of 80 plants. Vertical bars indicate standard errors.

Table 3. Responses of six local plant species to site treatments in a limestone quarry, 12 years after planting – Experiment 2. Mean height (m), mean DBHOB (cm) and mean health (1-5, 1 signifying dead, 5 signifying healthy). Species codes: *As = A. saligna, Da = D. aptera, Ed = E. decipiens*, *Eg = E. gomphocephala*. Survival rates of *B. attenuata* and *T. retusa* were too low to conduct analysis. Treatment codes: All= all treatments, +B= broadcast fertiliser, -B= no broadcast fertiliser.

Species	**Treatment**			
	Control		All	
	-B	+B	-B	+B
		Mean height (m) (S.E.)		
As	1.6(0.2)	1.6(0.1)	1.6(0.2)	1.6(0.5)
Da	1.4(0.2)	0.7(0.1)	1.3(0.3)	0.9(0.1)
Ed	6.8(1.1)	3.8(2.3)	3.4(2.3)	4.9(1.4)
Eg	6.2(2.3)	2.7(1.3)	4.3(2.7)	6.0(0.3)
		Mean DBHOB (cm) (S.E.)		
As	2.0(0.0)	1.2(0.8)	1.5(0.3)	2.8(0.6)
Ed	7.3(3.1)	5.7(2.7)	6.5(0.0)	6.2(2.2)
Eg	7.9(1.2)	5.3(1.2)	4.2(1.1)	5.1(1.3)
		Mean health (1-5) (S.E.)		
As	3.5(1.5)	2.5(0.5)	3.3(0.4)	2.3(0.3)
Da	5.0(0.0)	2.0(0.0)	4.0(1.0)	4.6(0.2)
Ed	4.5(0.5)	5.0(0.0)	4.0(1.0)	5.0(0.0)
Eg	3.5(0.5)	4.0(0.0)	3.5(1.5)	3.0(0.0)