PLANT SPECIES SUCCESSFULLY RECOLONISING REHABILITATED BAUXITE MINES

J.E.D. Fox, J.D. Majer and P. Sanford
School of Biology,
Western Australian Institute of Technology

J.E. Day and B.L. Glossop
Alcoa of Australia Limited, Pinjarra

Introduction

Information on plant species colonising mined areas is important in relation to investigations aimed at ensuring the continuing survival of revegetated sites to the stage of self regeneration.[7] In the present account we give details of colonising plants recorded in mined sites in relation to an exercise mainly concerned with ant recolonisation and reported elsewhere.[4]

Early attempts at revegetating bauxite pits have been detailed in several recent papers.[6,7]

More recent work seeks to incorporate a greater variety of species in early growth following mining by careful handling of topsoil.[1,6,8]

This report is concerned with two bauxite mining areas, Jarrahdale and Del Park worked by Alcoa of Australia. Both are jarrah (*Eucalyptus marginata*) forest localities in Western Australia approximately 45 km and 90 km SSE of Perth respectively.

The range of tree species which may be used for rehabilitating mined areas is restricted by the presence of the pathogenic fungus, *Phytophthora cinnamomi*. *P. cinnamomi* is the causal agent of jarrah dieback disease and is widely distributed in both mining areas.

The earliest forms of rehabilitation (Jarrahdale, 1966), were not ripped and often the top soil was not replaced evenly. Nursery reared, *P. cinnamomi* resistant trees, such as *Pinus pinaster*, *Eucalyptus maculata* and *Eucalyptus saligna* were planted as monocultures in rows and fertilizers were applied.

Later on rehabilitation involved battering down pit faces, general landscaping, more attention to top soil return, and deep ripping. Recently attention has been paid to the restoration of understorey vegetation. Research has shown that the majority of seed is in the top 2 cm of forest soil.[1,2,5,6,8] Currently direct seeding[1] and double stripping[8] are now employed together to restore the understorey vegetation and at least five tree species are selected for each pit.[4] This contrasts with the usual single species used earlier.[1] Trees are planted along contours and fertilizer is spread over the pit to aid understorey development.

Table 1 Plot number, main species, year, location and method of revegetation used.

Plot No.	Main Species	Year	Location	Method
1.	*Pinuspinaster*	1966	J	P
2.	*Pinus pinaster*	1970	J	P
3.	*Eucalyptus maculata*	1966	J	P
4.	*Eucalyptus maculata*	1970	J	P
5.	*Eucalyptus maculata*	1971	J	P
6.	*Eucalyptus maculata*	1976	D	P
7.	*Eucalyptus saligna*	1966	J	P
8.	*Eucalyptus saligna*	1969	J	P
9.	*Eucalyptus wandoo*	1969	J	P
10.	*Eucalyptus resinifera*	1970	J	P
11.	*Eucalyptus resinifera*	1973	J	P
12.	*Eucalyptus resinifera*	1974	J	P
13.	*Eucalyptus resinifera*	1974	D	P
14.	*Eucalyptus globulus*	1969	J	P
15.	*Eucalyptus calophylla*	1973	D	P
16.	*Eucalyptus calophylla*	1975	J	P
17.	Mixed *Pinus* spp.	1969	J	P
18.	Mixed *Eucalyptus* spp.	1970	J	P
19.	*Pinus pinaster*	1969	J	P
20.	*E.calophylla + Eresinifera*	1976	J	S
21.	*Trifolium subterraneum*	1976	J	S
22.	*E.calophylla + E.wandoo*	1977	J	P
23.	*E.calophylla*	1975	J	P
24.	Mixed *Eucalyptus* spp.	1976	D	P
25.	*Eucalyptus meullerana*	1968	J	P
26.	Nil	1978	D	-
27.	*Eucalyptus globulus*	1969	J	P
28.	*Eucalyptus resinifera*	1973	D	P
32.	*Eucalyptus resinifera*	1973	J	P
33.	Mixed *Eucalyptus* spp.	1973	J	P

Location J - Jarrahdale, D - Del Park
Method P - Planted, S - Seeded
Plots 29, 30, 31 were Forest Controls

The following variations were included in these plots:

Plot 19 : area cleared but not mined, so revegetation occurred on original soil.
Plot 20 : a considerable diversity of understorey vegetation induced by use of a variety of seeds.
Plot 21 : appeared pasture-like.
Plot 22 : was mulched with bituminised straw.
Plot 23 : incorporated double stripped topsoil.
Plot 27 : fresh topsoil used.
Plot 26 : no plant species recorded.

Method of sampling

For the survey twenty-three rehabilitated plots and two forest controls were selected at Jarrahdale, and seven mined plots and one control at Del Park.[4] Most of the mined plots had been ripped, topsoil returned, and planted at different times with either *P.pinaster* or a range of *Eucalyptus* species (Table 1).

Table 2 Species recorded in plots

(*not found in mined plots, only in forest control).

Acacia browniana
A.extensa
A.horridula
A.pulchella
A.saligna
A.urophylla
Adenanthos barbigerus
*Agrostocrinum scabrum**
Aira caryophyllea
Albizia lophantha
Astroloma ciliatum
Banksia grandis
Boronia spathulata
Bossiaea aquifolium
Bossiaea ornata
Briza maxima
B.minor
Casuarina fraserana
Centaurium spicatum
*Clematis pubescens**
*Comesperma virgatum**
*Conostylis serrulata**
Conostylis setosa
Cyathochaete avenacea
Danthonia setacea
Daviesia pectinata
Daviesia pressii
*Dryandra nivea**
Dryandra sessilis
Eucalyptus calophylla
E.marginata
E.muellerana+
E.resinifera+
Gompholobium knightianum
G.marginatum
G.preissii
Gnaphalium candidissimum
Grevillea wilsonii
*Hakea amplexicaulis**
Helipterum cotula
Hibbertia amplexicaulis
Hibbertia montana
Hovea chorizemifolia
*Hovea trisperma**
*Hypochoeris radicata**
Isotoma hypocrateriformis
Kennedia coccinea
Lasiopetalum floribundum
*Lechenaultia biloba**
Lepidosperma angustatum
*L.gracile**
L.tenue
Leucopogon capitellatus
L.oxycedrus
*Lomandra caespitosa**
*L.endlicheri**
L.hermaphrodita
*L.micrantha**
*L.preissii**
L.purpurea
L.sonderi
*Loxocarya flexuosa**
Macrozamia riedleii
Mirbelia dilatata
Neurachne alopecuroides
Opercularia echinocephala
Orobanche australiana
Oxylobium lanceolatum
*Patersonia sericea**
Persoonia longifolia
Phyllanthus calycinus
Pinus halepensis+
Pinus pinaster+
Platysace compressa
Platysace tenuissima
Podolepis gracilis
*Pteridium esculentum**
Scaevola pilosa
S.striata
Solanum nigrum
Sollya heterophylla
Stylidium amoenum
S.hispidum
Tetrarrhena laevis
Tetratheca viminea
Thysanotus dichotomus
Thysanotus multiflorus
Trachymene pilosa
Trymalium ledifolium
Waitzia paniculata
*Xanthorrhoea gracilis**
X.preissii
Xanthosia candida
X.heugelii
X.peltigera

\+ *E.muellerana* only in Plot 25
E.resinifera only in Plot 20
P.halepensis only in Plot 17
P.pinaster in Plots 1,2.

All field work was performed between December 1978 and February 1979. Each plot was halved and a 100 metre transect was marked out in each half. Only one transect was established in plot 33.

At 10 metre intervals along each transect, 1 metre square quadrats were established. Within each quadrat the number of individuals for each species was recorded. The plant species lists for each transect were summed by numbers of plants and tabulated for the plot sets. Table 2 lists 95 plant species identified. A further 24 were not identified to species, of which 3 did not occur in mined sites. Of the species listed 18 were not represented in mined plots and 4 were exotic tree species seedlings (see footnote to Table 2).

Some 64 species were recorded in the forest controls with 45 in plot 29, 29 in plot 30 and 26 in plot 31 or a mean for the three of 33 species. Plot 7, one of the oldest examined of the mined sites had the highest number of species recorded at 29, twelve years from planting (Fig.1). There was a trend of increased number of species with time from treatment. For example *Eucalyptus maculata* plots, numbers 6,5,4, and 3 had 11,17,14 and 22 species recorded respectively. The seeded plot, number 20 with 18 species at two years from treatment, and the double-stripped sample (number 23) with 24 species at 3 years, gave better species counts than others of the same age.

As techniques differed for the different sites no further consideration is given here to the development of species diversity as between plots in relation to time.

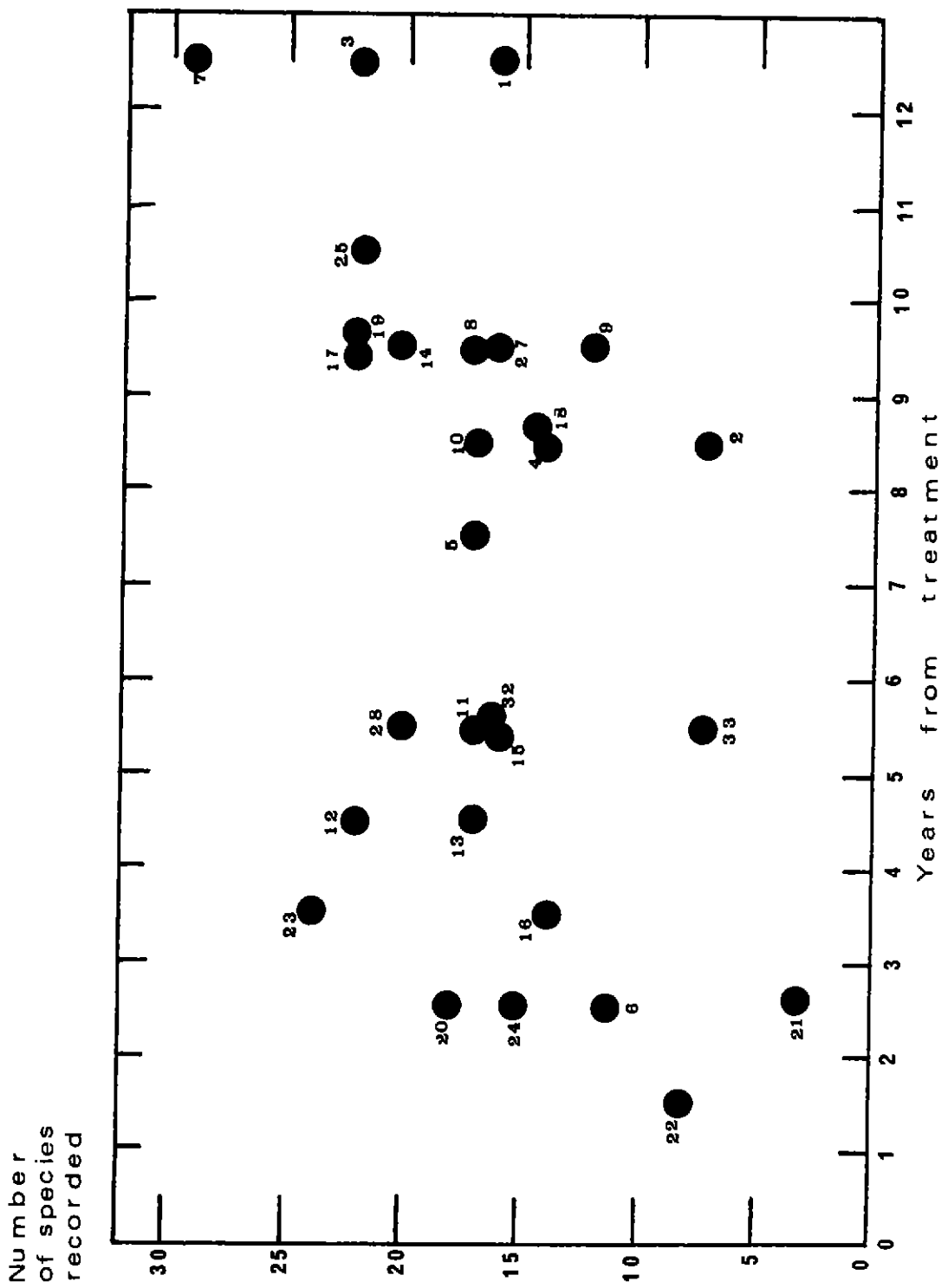

Figure 1 Numbers of species recorded for each site plotted against years from post-mining rehabilitation treatment. (Numbers as in Table 1).

Species frequencies and colonisation status

Firstly we consider the abundance of species in the forest control plots. The 10 most abundant species are listed in Table 3.

Table 3 Most abundant species in Forest Plots

Species	Numbers Present	
	Plots 29, 30, 31	Mined Plots
* *Lomandra hermaphrodita*	156	5
* *Lepidosperma tenue*	141	90
* *Lomandra sonderi*	136	7
* *Cyathochaete avenacea*	105	9
Loxocarya flexuosa	94	-
* *Conostylis setosa*	82	143
* *Lasiopetalum floribundum*	66	118
Lomandra micrantha	52	-
* *Hibbertia montana*	50	31
Trymalium ledifolium	47	304

* Present in all 3 forest plots

The majority of these 10 species are grass-like of the ground cover. Those species marked with an asterisk were the most 'frequent' being present in all 3 plots. If plot frequency only is considered then the other three species would be replaced by *Xanthosia peltigera*, *Eucalyptus marginata* and *Hibbertia amplexicaulis* with 42, 33 and 26 individuals respectively on the forest plots and 4, 9 and 19 in the mined plots.

E. marginata is the dominant species of the unmined forest, giving its name (Jarrah) to the formation. In the mined plots it was only represented in 2 of the 30 sites. Only *Trymalium ledifolium* (23 sites) *Conostylis setosa* (19 sites), *Lasiopetalum floribundum* (19 sites) and *Hibbertia amplexicaulis* (12 sites) can be considered as reasonably abundant in both forest and mine sites. The fact that *T. ledifolium* was present in only two of the three forest sites is of some interest.

A total of 15 species is listed in Table 4. The first 10 were the most abundant, with highest numbers of individual plants recorded in the mined plots. Of these, three species of Asteraceae (daisies) viz *Helipterum cotula*, *Gnaphalium candidissimum*, and *Waitzia paniculata*, were present in nine or fewer plots. Together with the exotic grass *Aira caryophyllea* they were not represented in the forest controls. These four annuals contribute little cover and cannot be considered as important species in terms of biomass. *A. caryophyllea* and *G. candidissimum* showed greater abundance sooner following post-mining rehabilitation than the other two (see Fig. 2). Numbers of *A. caryophyllea* showed a tendency to decline with time from treatment, suggesting that it behaves as a seral species in relation to shade.

The only other species listed in Table 4 and not represented in the forest controls was the legume *Mirbelia dilatata*. It is a woody shrub of the understorey in the Jarrah forest. It is particularly abundant in more open areas. It has 455 seeds g^{-1}[1] with 74 per cent germination after 63 days[5]. This species was most abundant in plot 11, perhaps a fortuitous event of little significance. We now consider the more important species recorded after mining.

Brief notes on the species of greatest abundance are given below.

Trymalium ledifolium in the family Rhamnaceae must be considered the most important coloniser. It was present in more mined plots than the other species of perennial, it was more abundant, and was of greater size than most of the species of Table 4. It is a well known fireweed shrub growing to about 1 m, and producing abundant seed. It is self pollinating. Seeds will germinate within 38 days[3] and there is evidence that ants assist in seed dispersal. This species was found in all of the plots >8 year from treatment ex-

Table 4 Most abundant species in Mined Plots, with most frequent species also considered.

	Mined Plots		Forest Control	
	Plot frequency	Total number of plants	Plot frequency	Total number of plants
Most abundant species				
*Helipterum cotula**	6	1713	-	-
Aira caryophyllea	14	877	-	-
*Gnaphalium candidissimum**	3	480	-	-
Trymalium ledifolium	23	304	2	47
Stylidium hispidum	16	265	2	15
*Waitzia paniculata**	9	245	-	-
Conostylis setosa	19	143	3	82
Boronia spathulata	19	125	2	20
Lasiopetalum floribundum	19	118	3	66
Opercularia echinocephala	20	104	1	3
Other species in >8 mined plots				
Xanthosia candida	18	56	1	8
Bossiaea ornata	14	58	2	3
Hibbertia amplexicaulis	12	19	3	26
Mirbelia dilatata	12	51	-	-
Platysace compressa	10	77	2	39

* These species drop out of the top ten if frequency is considered most important

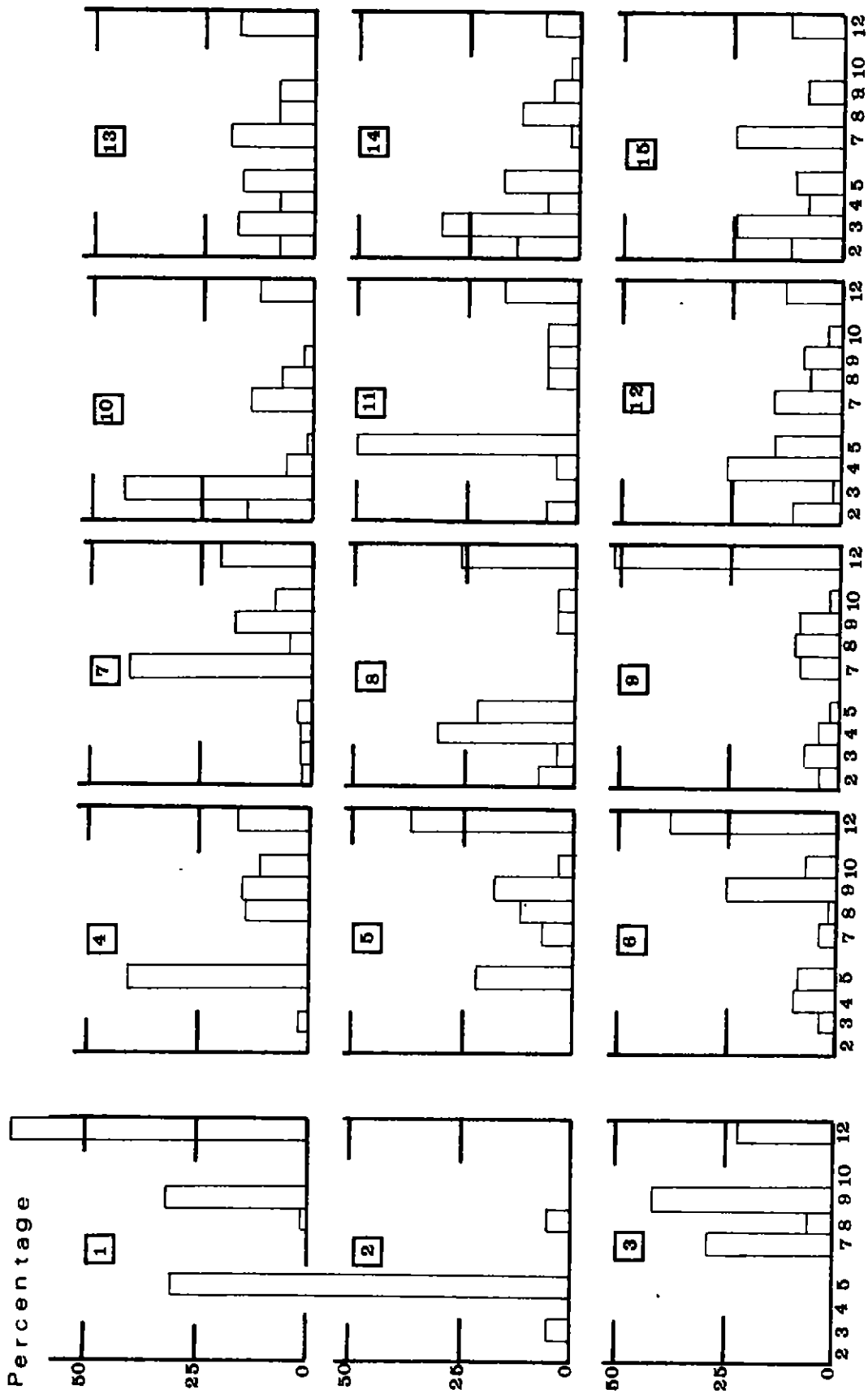

Figure 2 Percentage representation of 15 abundant species by age from post-mining treatment. (Calculated by summation of mean numbers per plot by one year age groups, using only those plots in a set for which the species was recorded). 1 *Helipterum cotula*, 2 *Gnaphalium candidissimum*, 3 *Waitzia paniculata*, 4 *Aira caryophyllea*, 5 *Stylidium hispidum*, 6 *Boronia spathulata*, 7 *Conostylis setosa*, 8 *Bossiaea ornata*, 9 *Lasiopetalum floribundum*, 10 *Platysace compressa*, 11 *Mirbelia dilatata*, 12 *Trymalium ledifolium*, 13 *Xanthosia candida*, 14 *Opercularia echinocephala*, 15 *Hibbertia amplexicaulis*.

cept for the 1970 *Pinus pinaster* plantation (plot 2) which had very few species recorded (Fig.1). It was particularly abundant with the older *E.saligna* (plot 7) and in the *E.resinifera* plots at Del Park (plots 13, 28). It was also frequent in the cleared but unmined sample (plot 19). Of the more recent plots it was not recorded in plot 22 but was well represented in plots 6 and 24, treated two years earlier. The plant will persist upto 10 years. *T.ledifolium* is killed by fire.

Stylidium hispidum is a rosette-form trigger plant (Stylidiaceae) with a flowering stalk to about 30 cm. Apart from the seeded plot 20 where one individual was recorded, it was not recorded from plots where treatment was more recent than 5 years before sampling. It was most abundant in the 1966 plots(1, 3 and 7). The species produces abundant seed and germination takes 51 days.[3] *S.hispidum* must be considered a late coloniser in comparison with *T.ledifolium*. Greatest density occurred in the unmined plot (19). It is a perennial herb, persisting for five years or more.

Conostylis setosa is a low clump-form perennial of rhizomatous stock in the family Haemodoraceae, growing to about 30 cm. Unlike the previous species discussed it is somewhat fire resistant and will sprout after burning. Seed will germinate in 45 days.[3] This species was more abundant on sites >7 years from treatment though it was present in six of the twelve plots sampled at 2.5 to 5.5 years from post-mining treatment. It was most frequently recorded in the unmined site (plot 19).

Boronia spathulata is a low perennial shrub which tends to favour moister sites. It is a member of the Rutaceae and produces few comparatively large seed. *B.spathulata* was most frequent on sites >9 years from treatment where 96 were recorded from 8 sites, compared with sites >3 years and <9 years in which 31 plants were recorded from 11 sites. Of the more recently treated sites it was most abundant in plots 15 and 13 both at Del Park. It was present in the unmined site and absent from areas less than 3 years from treatment.

Lasiopetalum floribundum was present throughout, in greatest abundance in plots 1 and 3. This species is a member of the family Sterculiaceae. It is a soft, hairy, undershrub which may grow quite fast. Seeds germinate in 51 days[3], but viable seed production is low. The limited evidence suggests that it increases in importance with time from disturbance-of the abundant species it was second in frequency to *Conostylis setosa* in the forest controls (Table 4).

Opercularia echinocephala in the Rubiaceae is a herbaceous perennial of low stature. It produces abundant seed which probably germinates readily. It is self pollinated. It was recorded over the range of times from treatment following mining, but tended to be most abundant in the past five years (Fig.2). This species may be considered an early pioneer, it was scarce in the undisturbed forest controls (Table 4) and was not recorded from plot 19.

Xanthosia candida is another herbaceous species which persists for several years. It is a member of the family Apiaceae and species in this genus have a comparatively lengthy germination period of about 90 days[3]. It produces a lot of seed. It was equally distributed over the range of sites examined following mining, though not well represented in the forest controls.

Bossiaea ornata and *M.dilatata* are the only legumes (Fabaceae) noted in Table 4. *B.ornata* produces abundant seed, with 450 g^{-1}[1]. It is a fireweed species, with seed stimulated by fire. The seed are taken by ants. Germination will occur within 28 days[3]. *B.ornata* is a low shrub to about 70 cm tall. It was well represented in the older plots, but in the plots more recently treated it was much commoner at Del Park than at Jarrahdale. It was particularly common with Eucalyptus resinifera (plots 13 and 28).

Hibbertia amplexicaulis is a low scarcely erect sub-shrub of the Dilleniaceae. It was nowhere as abundant in mined plots as in the forest controls. There was no discernable pattern of frequency in relation to time from treatment. This species produces few seed, and the germination is long at 56 days,[3] regeneration is lignotuberous following fire. *H.montana*, a frequent species of the unmined forest (Table 3), was present in 8 mined plots with a total of 31 records, 13 from plot 23.

Platysace compressa is another small plant of the family Apiaceae. There was a tendency for this plant to be more frequent in the earlier years (Fig.2). However the distribution of numbers was skewed with 36 per cent of all recorded individuals in plot 23, It was also well repsented in the seeded plot 20.

Of the species so far described none are of the Proteaceae. Five species of this family were recorded in mined plots. Of these *Adenanthos barbigerus* was most frequent, present in seven plots, and *Dryandra sessilis* most numerous with all individuals recorded in the unmined site, plot 19. The latter species is a fast growing pioneer on cleared gravel pit sites within the jarrah forest, and is often abundant following fire. It sets prolific seed but does not regenerate from root stock, growing as a tall single stemmed shrub to 5 m. *A.barbigerus* is a low shrub <1 m which readily re-grows from lignotuber material after fire, probably producing less seed. This species was most numerous in areas treated >9 years earlier. *Persoonia longifolia*, a small tree of the understorey, was present in four plots. *Banksia grandis* a larger understorey species was present in plots 7 and 19 only and *Grevillea wilsonii* a sprawling low shrub <2 m was only recorded from plot 19.

By contrast leguminous species were well represented in the samples. In addition to *Bossiaea ornata* and *Mirbelia delatata* (Table 4) six species of *Acacia*, two of *Daviesia*, two *Gompholobium* species, another *Bossiaea* and one species each of *Hovea*, *Kennedia*, *Oxylobium* and *Albizia lophantha* were recorded. A number of

these species show high germination rates after the seed is heated[5] and all are prolific seeders. Of the more frequently recorded *Acacia* species *A.urophylla* was most frequent in sites >9 years from treatment. This species is a low (to 2-3 m) undershrub able to tolerate shade. *A.pulchella* (170 seeds g^{-1}) and *A.extensa* (80 seeds g^{-1}) are pioneers, prolific after fire[5], but tend to die out as shade develops. These were recorded on 7 and 8 plots respectively, mainly <5 years from post-mining treatment at much greater density than *A.urophylla*. *Kennedia coccinea*, a twiner, was present at 8 sites, all <6 years from treatment.

Other species of interest include *Phyllanthus calycinus* a small perennial shrub of the Euphorbiaceae which sets abundant seed and is often seen as a pioneer. This was present at 8 sites >4 and <10 years from treatment. The understorey tree *Casuarina fraserana* was scarce, with single recordings only in plots 7, 19 and 28.

Discussion

The present account must be considered of a preliminary nature. However some areas of interest may be noted in relation to forest development and future studies.

The use of mixed eucalypts as against pure plantings[1] is now preferred[4]. The limited data available from the present study do not allow a rigorous analysis of how mixtures may affect species diversity. We note that amongst the earlier plantings plot 18 was a mixed planting. This had a mean of 14 species recorded compared with 7, 14 and 17 (mean 13) from plots 2, 4 and 10 treated at the same time. At five years from treatment plot 33 had only 7 species compared with 17, 16, 20 and 16 in plots 11, 15, 28 and 32. The major and irregular contributions to numbers of individual plants recorded, from the annual grass *Aira caryophyllea* and the three common daisies, suggest that the e should be discounted in examining biomass development of shrub or understorey layers.

Of equal interest is a consideration of balance between the low herbaceous layer and the shrub component. Excluding *Trymalium ledifolium*, *Hibbertia montana*, *Lasiopetalum floribundum* and *Conostylis setosa* from the list given in Table 3, we find the remainder are monocotyledons.

Two of the six species were entirely unrecorded from mined sites (viz *Loxocarya flexuosa* and *Lomandra micrantha*). The other four were found only on 3 to 5 sites, generally in low numbers apart from *Lepidosperma tenue* in the unmined cleared plot (19) and in plot 7 one of the older set of treated areas. Plot 19 accounted for 70 per cent of the records of this group of species, and 80 per cent of the records were due to *L.tenue* in plots 7 and 19. Ninety per cent of all occurrences of the group were in plots treated nine or more years prior to sampling. No combination of treatments post-mining has resulted in regeneration of numbers of these species so abundant in the low herbaceous layer of the jarrah forest.

The presence and abundance of a number of species (particularly legumes; *Trymalium ledifolium* and *Phyllanthus calycinus*), often referred to as fire-weeds, indicate that these species readily colonise the new sites, provided seed is available. Double-stripping of topsoil enhances species numbers early on (plot 23, Fig.1) but whether further increases in diversity are more likely than, for example, with the type of treatment rendered to plot 7, must await further development. Successional theory suggests that as the stands thicken up some intolerant species will decline and a number of shade bearers will increase. Some of these trends are already evident as shown in Fig.2.

Members of the Proteaceae have not returned to the mined areas in any significant numbers. This reflects poor dispersal and relatively heavy seed. There is some evidence that replacement of proteaceous understorey, particularly by legumes, may be beneficial in restricting the spread of *Phytophthora cinnamomi*[5]. The new stands produced all tend to be unique with patterns affected by species planted, the local topography and chance invasion.

Acknowledgements

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