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Recovery of Terrestrial Orchids in the Post-Mining Landscape

Margaret Collins*

School of Earth and Geographical Sciences (Soil Science Discipline), Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, WA 6009 Australia. Email: mcollins@cyllene.uwa.edu.au

John Koch

Alcoa World Alumina Australia, P.O. Box 252, Applecross, WA 6953 Australia.

Mark Brundrett

School of Plant Sciences, Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, WA 6009 Australia.

Krishnapillai Sivasithamparam

School of Earth and Geographical Sciences (Soil Science Discipline), Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley, WA 6009 Australia.

Abstract. Currently, Alcoa World Alumina Australia mines and rehabilitates ca. 550 ha of jarrah forest each year at two open-cut bauxite mines in Western Australia. The aim of Alcoa's rehabilitation program is to re-establish a functional and self-sustaining jarrah forest ecosystem in these mined areas. Many indigenous geophytic plant species, however, fail to re-establish or do so very slowly. Indigenous terrestrial orchids form a significant proportion of the species difficult to re-establish. The dominant source of orchid propagules within the rehabilitation areas is wind-dispersed seed. Recruitment of new plants is dependent on availability of both viable seed and appropriate mycorrhizal fungi in the soil of suitable microhabitats at the beginning of the wet season. Flora surveys were undertaken to determine orchid species and their density in a temporal sequence of rehabilitation areas, so as to establish the sequence of species recovery. Total orchid population and clonal orchids were found to have returned to rehabilitation areas within 5 years at densities not significantly different from those of adjacent unmined forest. Numbers of total species and clonal species also were found to have returned to rehabilitation areas within 5 years at densities not significantly different from those of adjacent unmined forest. Orchid species identified as disturbance opportunists returned to rehabilitation areas within 5 years with densities increasing during the following 10 years but dropping to numbers not significantly different from those of adjacent unmined forest after 25 years. No disturbance opportunists were found in any unmined forest. Future studies will investigate the recovery of selected individual species in rehabilitation areas, vegetation associations of these species in both unmined forest and rehabilitation areas, and the diversity of their mycorrhizal fungi.

Key words: terrestrial orchids, jarrah forest, mining rehabilitation

Introduction

The southwest botanical province of Western Australia is known for its high floristic biodiversity. The two major forest ecosystems occurring within this floristic province are karri (*Eucalyptus diversicolor* F.Muell.) and jarrah (*Eucalyptus marginata* Donn ex Smith) forests (Figure 1). Karri forest is limited to high rainfall areas of the lower southwest. Jarrah forest is delimited by the Darling Scarp in the west, the 750-mm isohyet in the east (the limit of mallet-wandoo woodlands in the north and marri-wandoo woodlands in the south), and the climatic boundary between dry and more moderate Mediterranean climates in the south (Beard 1990). Jarrah forest is divided into northern and southern sub-regions along a poorly defined line, where ironstone gravels become less prevalent, and understory flora become more like that of the karri forest (Beard 1990). Alcoa World Alumina Australia, which was first granted the mining lease to the northern jarrah forest of southwest Western Australia in 1961, has been mining bauxite since 1963 at three open-cut mine sites (Figure 1). Currently, the company mines and rehabilitates ca. 550 ha of jarrah forest each year at the Huntly and Willowdale mine sites. The third mine at Jarrahdale, which operated 1963–1998, has been rehabilitated and decommis-

* Corresponding author.

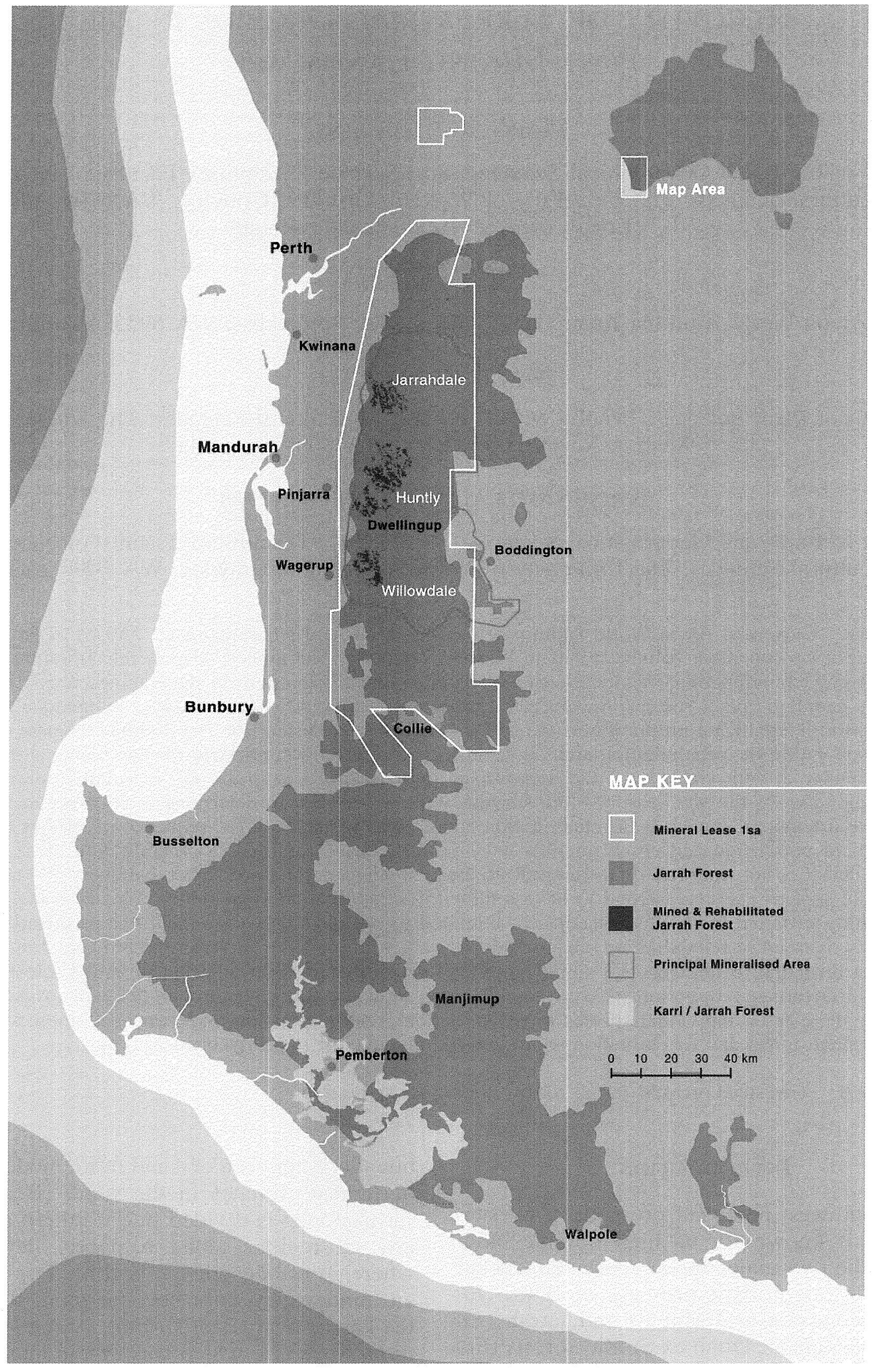

FIGURE 1. Southwest region of Western Australia showing extent of an Alcoa mining lease in relation to jarrah and karri forests.

sioned. Originally the aim of rehabilitation was to establish vegetation cover as quickly as possible, often using fast-growing exotic species or non-indigenous Australian species. During the period of the lease, Alcoa has adopted a process of continuous improvement in its environmental management and mine-rehabilitation standards. The present aim of rehabilitation is to re-establish a functional and self-sustaining jarrah forest ecosystem in areas that have been mined for bauxite (Elliott et al. 1996). This means re-establishing, as near as is practicable, the pre-mining vegetation structure, species diversity, and forest function.

Many indigenous geophytic plant species either fail to re-establish or do so very slowly within rehabilitation areas (Koch & Ward 1994, Koch et al. 1996, Grant & Koch, 2003). Terrestrial orchids represent ca. 20% of difficult to re-establish species. The recovery of orchids in mine rehabilitation areas has been expected to occur through the natural dispersal of seed from surrounding unmined forest. Orchid seed, minute and naturally dispersed by wind, has been known to travel substantial distances. Reports of distances greater than 100 km have been made in several instances (Rasmussen 1995). The orchid flora of the southwest botanical province ranks among the most diverse terrestrial orchid floras in the world with more than 340 taxa identified (Hoffman & Brown 1998). At least 73 of these taxa have been found within the jarrah forest (A. Brown pers. comm.). All but one of these indigenous orchids are terrestrial, tuberous, summer deciduous, and mycorrhizal. The exception, *Cryptostylis ovata* (R.Br.), also is terrestrial, tuberous, and mycorrhizal but evergreen. Orchid mycorrhizal fungi are required for the germination of seed and for nearly the complete nutrition of protocorms and seedlings up to the development of photosynthetic capacity. Generally mycorrhizal relationships are regarded as symbiotic, in the sense that they are mutualistic, with both partners deriving benefits from the relationship (Johnson et al. 1997). Orchid mycorrhizal relationships are atypical, as nutrient flow is thought to be unidirectional—from fungus to plant (Gebauer & Meyer 2003, Smith & Read 1997). The degree of dependence on mycorrhizal fungus and the specificity of this relationship may be variable, with some terrestrial orchid species regarded as particularly vulnerable to environmental disturbance because of their dependence on a highly specific fungus (this is especially true for achlorophyllous species) (Matsuhara & Katsuka 1994, Andersen & Rasmussen 1996, Perkins et al. 1995).

Soil disturbance is known to reduce the inoculum potential of soil fungi through disruption of the hyphal network and subsequent loss of infectivity (Hutton et al. 1997, Jasper et al. 1989a, 1989b). The stripping and respreading of topsoil in bauxite mining causes severe disruption of the hyphal network and therefore greatly reduces the inoculum potential of orchid mycorrhizal fungi. Recruitment of new plants in bushland is dependent on availability of both viable seed and the appropriate mycorrhizal fungi in the soil of suitable microhabitats at the beginning of the wet season. Low recruitment rates from natural seed dispersal observed in bushland in Western Australia may be the result of the patchy distribution of the mycorrhizal fungi in the soil and the scarcity of suitable microhabitats in the landscape (Batty et al. 2001, McKendrick et al. 2002). Establishment of orchids in rehabilitation areas requires the availability of viable seed, recovery of the inoculum potential of mycorrhizal fungi, and establishment of suitable microhabitats through the regrowth of vegetation.

The aim of this project is to examine a temporal sequence of bauxite mine rehabilitation areas and adjacent unmined areas of jarrah forest to determine the diversity and frequency of occurrence of terrestrial orchids in both. Preliminary results are presented in this paper.

Materials and Methods

The Jarrahdale bauxite mine is located along the Darling Scarp near the town of Jarrahdale, 55 km southeast of Perth in Western Australia. The climate is dry Mediterranean with a mean annual rainfall of 1220 mm during the winter-wet season. Mining commenced at Jarrahdale in 1963, and the region was actively mined until 1998; rehabilitation was completed in 2001, and the site was decommissioned in 2002. In the bauxite mining process, large earth-moving equipment removes the soil covering the bauxite as two layers, topsoil (depth 10–15 cm) and overburden (depth 15–50 cm). The overburden is stockpiled next to the pit, and the topsoil is used for direct return at another site to minimize loss of propagules of both plants and mycorrhizal fungi. After removal of the bauxite layer (2–5 m depth), the pit is rehabilitated. In the post-mining rehabilitation process, pit walls are battered down, and the pit is landscaped. Overburden and topsoil then are respread in the correct order, and the area is ripped (to a 1.5-m depth), seeded, and fertilized. The current seeding mixture contains seed of the two dominant tree species—*Eucalyptus marginata* (jarrah) and *Corymbia calophylla* (Lindl.) K.D.Hill & L.A.S.Johnson (marri)—along with more than 60 understory species (Nichols et al. 1991).

Both the seeding mix and the soil seed bank in respread topsoil are valuable sources of propagules for revegetation of many plant species. Orchid seed, however, has never been added to the seed mixtures used for revegetation. Because the orchid soil seed bank in southwest Western Australia is known to be short-lived (Batty et al.

2000), respread topsoil is not likely to be a significant source of viable orchid propagules.

Orchid Survey

Single-belt transects (5 m by 50 m), each consisting of ten contiguous 5 m × 5 m quadrats, were established in four replicates of 1-, 5-, 10-, and 15-year-old rehabilitation areas (established in 2001, 1997, 1992, and 1987 respectively) and in adjacent unmined forest at Jarrahdale, Western Australia, in autumn 2002. Additionally, two transects were established in 27-year-old rehabilitation areas with an overstory of marri, and a single transect was established in a 26-year-old rehabilitation area; each was paired with transects in adjacent unmined forest. These three transects are identified as >25-year-old rehabilitation areas. Two transects also were established through populations of *Cryptostylis ovata* in the unmined forest (a total of 40 transects). Each transect was scored for the number of orchid species present and number of plants of each species in each quadrat during the 2002 growing season. Data also were collected on surrounding vegetation cover and structure, plant species present, and litter cover.

Data Analyses

All data were analyzed using GenStat Version 7, Lawes Agricultural Trust, Rothamsted Experimental Station.

Results

Orchids were found to have re-established in all rehabilitation areas except the 1-year-old rehabilitation areas (established 2001). The oldest transects had the highest mean density of orchids (Figure 2A); however, this only was significantly different (at $P \leq 0.05$) from 1- and 5-year-old rehabilitation areas. The orchid density of 1-year-old rehabilitation areas was significantly less than all other age categories. Orchid density in unmined forest was highly variable; and, despite large differences in the mean density of orchids, none of the forested areas differed significantly from each other or from their adjacent rehabilitation areas.

The mean number of orchid species present for 1-year-old rehabilitation areas was significantly different (at $P \leq 0.05$) from all other rehabilitation areas and forest transects (Figure 3A). The mean numbers of species in forest adjacent to the >25- and 5-year-old rehabilitation areas differed significantly from each other but not from other forested areas or from their adjacent rehabilitation areas.

As neither orchid density nor species number revealed significant changes with time past 5 years, the data for clonal orchids was examined separately. The mean density of clonal orchids for >25-year-old rehabilitation areas differed significantly (at $P \leq 0.05$) from all other rehabilitation areas and forested areas, except for those adjacent to 15- and >25-year-old rehabilitation areas. These forested areas, however, did not differ significantly from the rehabilitation areas or other forested areas (Figure 2B).

The mean number of clonal orchid species (Figure 3B) in 1-year-old rehabilitation areas was significantly lower than in all other rehabilitation and forested areas (at $P \leq 0.05$), but the number of clonal species did not differ significantly from adjacent forested areas. The 15- and >25-year-old rehabilitation areas had a higher mean number of species present but differed significantly only from the 1-year-old rehabilitation area and its adjacent forest.

Orchid species identified as disturbance opportunists were scored for all age rehabilitation areas and forest. The mean number of disturbance opportunists (Figure 3C) in rehabilitation areas that were 1, 5, and >25 years old were significantly lower than in 10- and 15-year-old rehabilitation areas (at $P \leq 0.05$). No disturbance opportunists were found in any of the forest sites.

Discussion

The recovery of flora in post-bauxite mining rehabilitation areas may well follow the "initial floristic composition" model (Koch & Ward 1994, Grant & Loneragan 2001), that is, the flora composition immediately following disturbance determines future shifts in dominance. In the post-mining landscape, the initial composition is determined by the composition of both the seeding mixture and the soil seed bank in respread topsoil. Alcoa's rehabilitation procedures originally consisted of planting exotic tree species (e.g., *Pinus pinaster*) but were later modified to seeding with mostly leguminous understory species and non-indigenous eucalypts (e.g., *Eucalyptus resinifera*). More recently, rehabilitation areas have been seeded with indigenous tree species and a broader range of understory species and then planted with tissue-cultured recalcitrant taxa (Grant & Koch 2003). Orchid seed, however, has never been included in seeding mixtures, and the soil seed bank is not expected to provide viable propagules (Batty et al. 2000). Orchids therefore are not expected to re-establish rapidly.

Natural recruitment of terrestrial orchids is low compared to the number of seeds they pro-

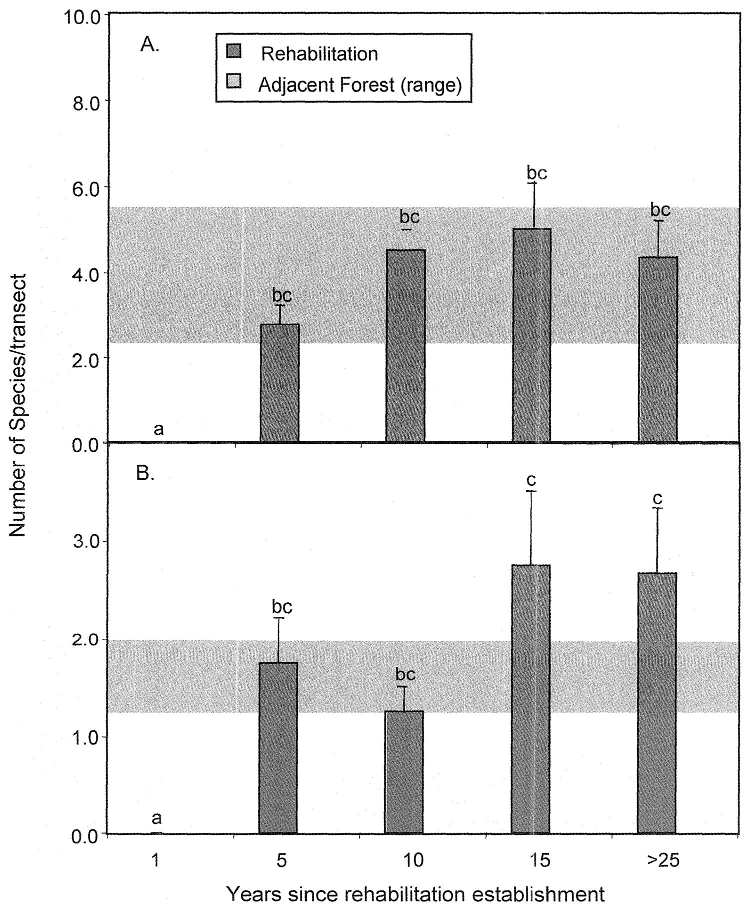

FIGURE 2. Mean number of orchid species found in a temporal sequence of transects in rehabilitation areas and adjacent unmined forest. For 1-, 5-, 10-, and 15-year-old rehabilitation areas, n = 4; for >25-year-old areas, n = 3. **A.** All orchid species. **B.** Clonal orchid species. Transect area 0.025 ha (5 m × 50 m). Vertical bars represent SE (standard error). Columns identified by the same letter are not significantly different.

duce (5000–30,000 seeds/pod) (M. Collins unpubl. data, Batty 2001). Recruitment in rehabilitation areas will be dependent on seed set in the surrounding forest, adequate dispersal, and the recovery of soil microflora with the progressive build up of organic matter. The survey results indicate that orchids re-establish in mined areas within 5 years in numbers that are not significantly different from those in unmined forest. Because of the dependence of terrestrial orchids on their mycorrhizal fungi for germination of seed, nutrition of protocorms, and development of adult plants, their presence may be regarded as an indicator of the recovery of their mycorrhizal fungi in the soil environment. Orchid mycorrhizal partners—rhizoctonia-like fungi primarily found in the coarse fraction of soil organic matter (partially decomposed litter) (Brundrett et al. 2003)—are expected to occur early in the succession of species in the recovery of soil microflora.

The recovery of orchids with differing growth habits will influence the future diversity and population size of orchids within the rehabilitation areas. Clonal orchids increase population size quickly because of their primarily vegetative reproductive strategy. These species, absent from 1-year-old rehabilitation areas, were present in 5-year-old and older areas. In the forests, Grant and Koch (2003) found that the highest densities of any indigenous orchids were of clonal species (TABLE 1). These species re-established in rehabilitation areas with densities reaching ca. 10% that of unmined forest in the >10-year-old rehabilitation area. Other species (except disturbance opportunists) generally were present as a much lower percentage of the premining density. Considerable time, probably

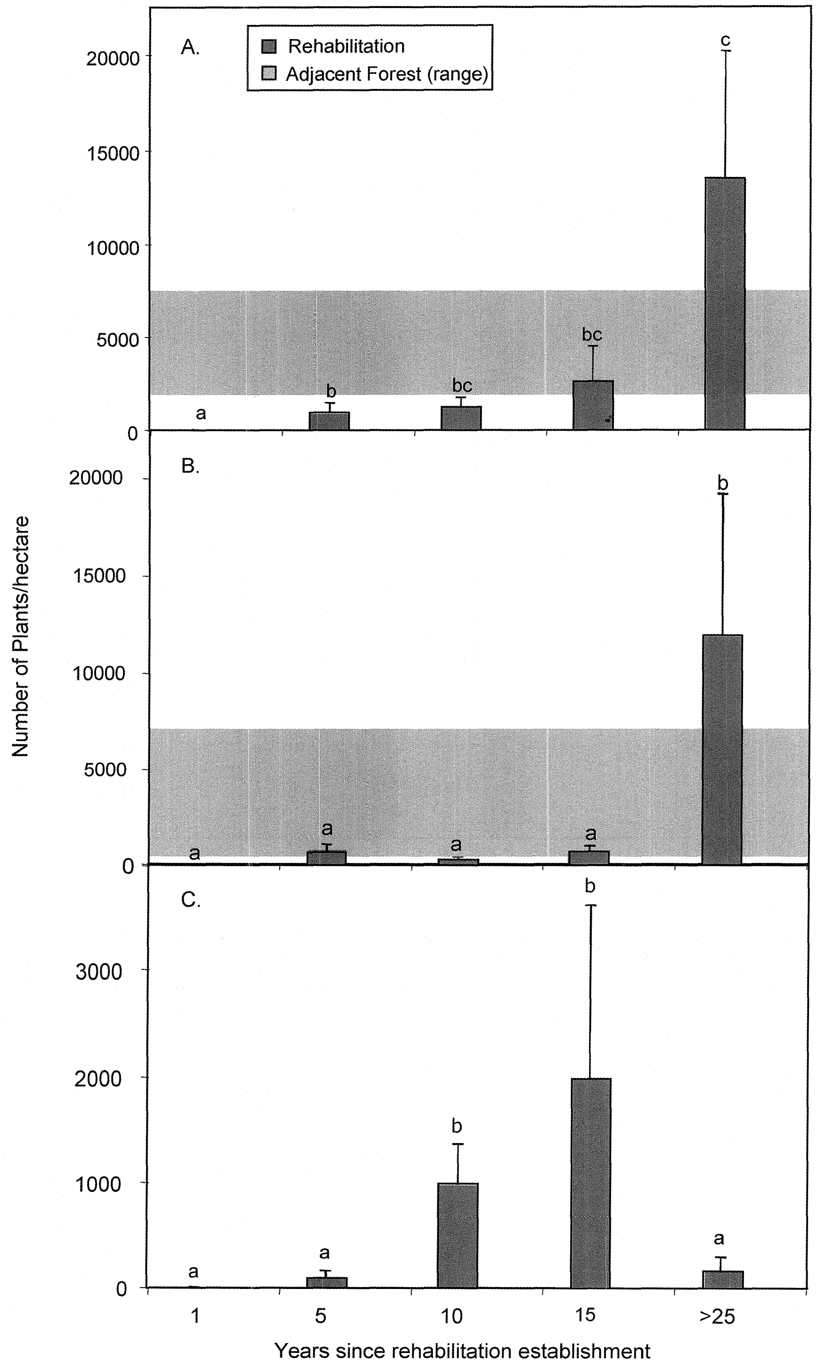

FIGURE 3. Mean density of orchids (plants ha^{-1}) found in a temporal sequence of transects in rehabilitation areas and adjacent unmined forest. For 1-, 5-, 10-, and 15-year-old rehabilitation areas, n = 4; for >25-year-old areas, n = 3. **A.** All orchids. **B.** Clonal orchids. **C.** Disturbance opportunists. Vertical bars represent SE. Columns identified by the same letter are not significantly different.

TABLE 1. Mean density of orchids (plants ha^{-1}) found in permanent vegetation monitoring plots by Alcoa, adapted from Grant and Koch (2003). Species have been separated by growth habit and sorted by decreasing forest density. Species names in bold are absent from either rehabilitation areas or forest. A single asterisk (*) refers to weed species, and a double asterisk (**) refers to an indigeneous species not normally found in jarrah forest.

Orchid species		Mean density (no./ha^{-1})		
Scientific name	Common name	Forest	All rehab	>10 yr old
Clonal species				
Cyrtostylis robusta	Mosquito orchid	3515.8	0.2	0.0
Caladenia flava	Cowslip orchid	2870.5	138.5	271.0
Pterostylis nana	Slender snail orchid	2694.8	133.3	250.0
Leporella fimbria	Hare orchid	607.0	0.4	0.0
Pterostylis vittata	Banded greenhood	520.3	60.5	119.3
Pyrochis nigricans	Red beaks	237.6	21.3	42.0
Caladenia reptans	Little pink fairy orchid	129.5	1.4	2.3
Cryptostylis ovata	Slipper orchid	46.2	**0.0**	0.0
Microtis media	Common mignonette orchid	3.4	889.5	1742.7
Other species				
Thelymitra crinita	Blue lady orchid	1183.6	1.5	3.1
Eriochilus dilatatus	Common bunny orchid	709.6	2.7	5.0
Thelymitra macrophylla	Scented sun orchid	399.8	0.4	0.8
Pterostylis recurva	Jug orchid	171.2	17.6	34.8
*Disa bracteata**	South African orchid	41.7	210.4	336.6
Cyanicula sericea	Silky blue orchid	22.5	0.2	0.4
Prasophyllum elatum	Tall leek orchid	20.3	**0.0**	0.0
Pterostylis barbata	Dwarf bird orchid	16.9	0.8	0.0
Prasophyllum brownii	Christmas leek orchid	15.8	0.2	0.0
Caladenia macrostylis	Leaping spider orchid	13.5	17.6	28.7
Lyperanthus serratus	Rattle beaks	11.3	**0.0**	0.0
Elythranthera brunonis	Purple enamel orchid	2.3	0.4	0.8
Diuris carinata**	Tall bee orchid	**0.0**	1.2	2.3

several decades, will need to elapse for populations of many orchid taxa to reach pre-mining densities and for diversity to be re-established (FIGURE 4).

The species data of Grant and Koch (2003) were grouped so as to separate species into the following categories: clonal species, disturbance opportunists, exotic species, and other species. The proportion of species in each category is compared with those of the current study in TABLE 2. The results of each study were generally similar for each species category, with the exception that the current study found no exotic species in forest sites. This may be an artifact of the current study's reduced sampling area, or these species may be responding to forest disturbance from causes other than mining in the earlier study.

Three species were identified as disturbance opportunists from a study of long-term vegetation survey work by Grant and Koch (2003): *Microtis media* R.Br., *Disa bracteata* Sw., and *Caladenia macrostylis* R. Fitzg. We found disturbance opportunists most abundant in 10- and 15-year-old rehabilitation areas, but density dropped dramatically in older sites. Bonnardeaux presented work at the IOCC II that showed a high diversity of fungal endophytes forming mycorrhiza with *D. bracteata* (synonym *Monadenia bracteata*). This naturalized South African species is among the most common of the disturbance opportunists in the rehabilitated areas. The ability to form mycorrhiza with diverse fungi may be advantageous in early recovery of flora. Other edaphic qualities or vegetation structural elements present only in young rehabilitation areas may provide a conducive environment for these species, e.g., low soil organic matter, intense shade, and lack of competition. The ecology of *D. bracteata* and other disturbance opportunists need to be examined further to determine if these species have the potential to be utilized as indicator species in the progress of vegetation recovery.

At present, we are examining the relationship between age of rehabilitation area and density of selected individual species. Future work is directed to several areas; firstly, we are examining the vegetation structure and species diversity associated with the occurrence of individual orchid species in rehabilitation areas and unmined forest. We also have carried out seed-baiting ex-

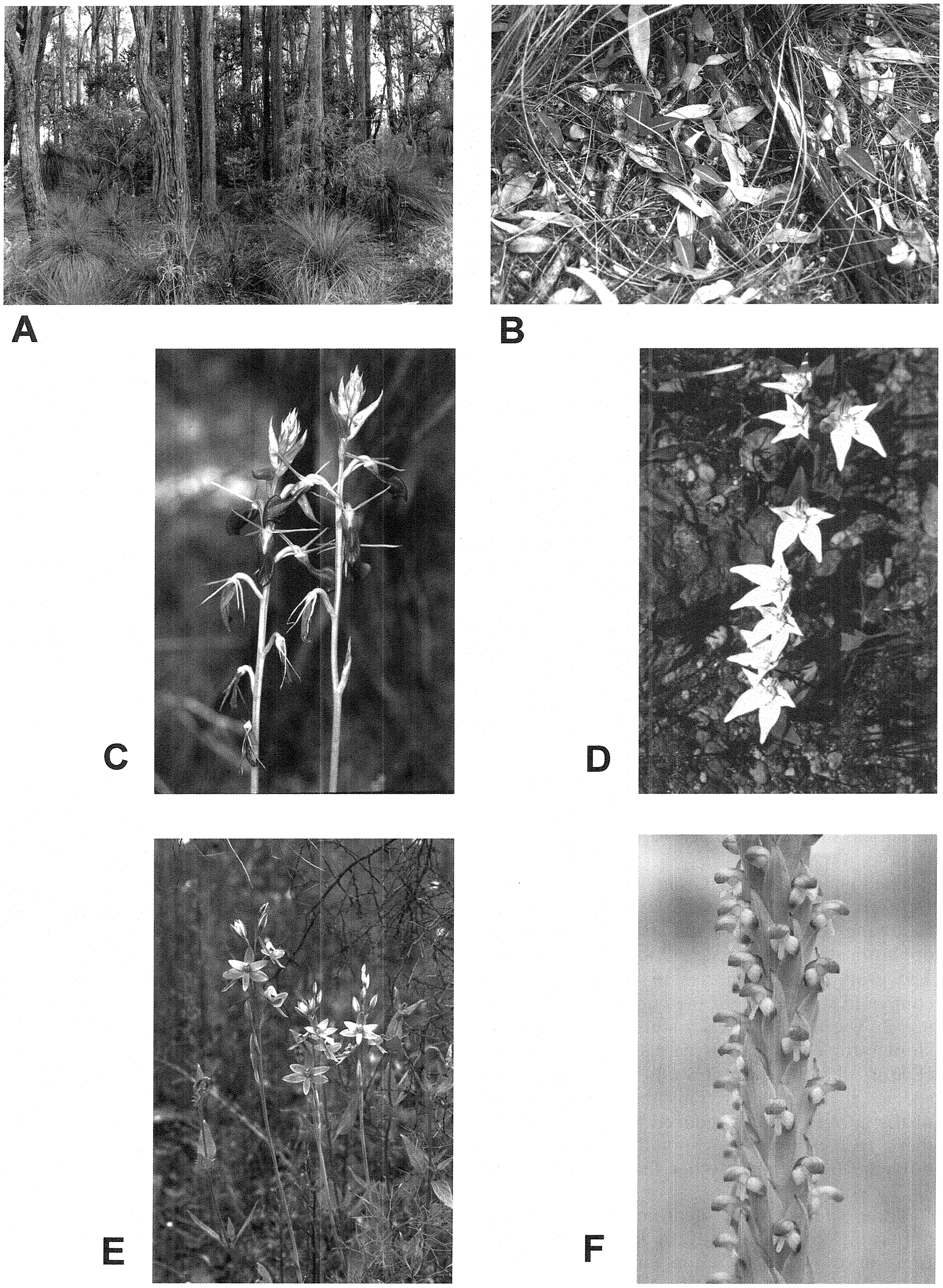

FIGURE 4. Native orchid habitat and species in southwest region of Western Australia. **A.** Un-mined jarrah forest. **B, C.** Slipper orchid (*Cryptostylis ovata*). **D.** Cowslip orchid (*Caladenia flava*). **E.** Blue lady orchid (*Thelymitra crinita*). **F.** South African orchid (*Disa bracteata*).

TABLE 2. Comparison of the number of orchid species of differing growth strategies found in the Alcoa retrospective study (Grant & Koch 2003) with data from the current project.

Orchid species category	Alcoa survey			Current study		
	Forest	All rehab	>10 yr old	Forest	All rehab	>10 yr old
				No. spp.		
Clonal	8	7	5	7	5	5
Disturbance opportunists	2	2	2	0	2	2
Exotic species*	1	1	1	0	1	1
Other species	10	9	7	7	5	5
Total	21	19	15	14	13	13
Total area surveyed (ha)	4.44	25.88	13.08	0.55	0.45	0.175

* The exotic species *Disa bracteata*, is also a disturbance opportunist.

periments to determine the presence or absence of appropriate mycorrhizal fungi in the topsoil of both forest and rehabilitation areas, and will be examining the diversity of fungal endophytes associated with selected orchid species.

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