Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

RESTORATION OF BANKSIA WOODLAND AFTER THE REMOVAL OF PINES AT GNANGARA: SEED SPECIES REQUIREMENTS AND PRESCRIPTIONS FOR RESTORATION

A report prepared on behalf of the
Department of Environment and Conservation
for the Gnangara Sustainability Strategy

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Report for the Department of Environment and Conservation

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This document has been commissioned/produced as part of the Gnangara Sustainability Strategy (GSS). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnangara groundwater system. For more information go to www.gnangara.water.wa.gov.au

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1 Introduction

The State Government had made a decision to clear the three pine plantations on the Gnangara groundwater system, located north of Perth, by 2029. After the pines are harvested some of this area will be restored to native woodlands. The priority is to reconnect intact remnants of native vegetation that are located throughout the pine plantations with surrounding bushland areas by restoring strategic ecological linkages.

The Department of Environment and Conservation (DEC), through the Gnangara Sustainability Strategy (GSS), has identified up to 19 potential ecological linkages throughout the pine plantations on the Gnangara groundwater system (hereafter referred to as the GSS area) (Brown *et al.* 2009). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnangara groundwater system. The proposed ecological linkages cover 15,500 hectares and although they incorporate existing bushland remnants, a portion of each linkage will require restoration. In total approximately 9300 hectares, or 60% of the area covered by the ecological linkages, requires restoration. The establishment techniques and costing for such restoration is still to be determined.

DEC has established restoration trials using direct seeding across cleared plantation compartments annually since 2001 to determine the most successful and cost-effective techniques for restoring post-pine sites with native vegetation. The success of these trials was assessed in 2004 (Reid *et al.* 2004) and 2008 (Maher *et al.* 2008). This report aims to compare the techniques used in the DEC trials to those of other companies so that best-practice prescriptions can be determined for future restoration. Key components of the report include:

1. Finalise the prescriptions for restoration:
   Based on best-practice techniques, the requirements for preparing the site for restoration will need to be determined. This will require a literature review of restoration techniques on the sandy soils of the Swan Coastal Plain. The prescriptions will be based on the trials undertaken by the DEC between 2001 and 2008, restoration literature and the experiences of Rocla Quarry Products and Kings Park in their restoration efforts.

2. Determine species lists for seeding:
   Utilise studies conducted by the DEC, restoration literature and previous work on this topic, to determine a species list(s) taking into account soil type, vegetation complex, wetland/upland location and seed availability of target species within the areas that require restoration.

3. Costing of restoration:
   Once the restoration prescription options have been finalised the costing of each technique will need to be determined. This will need to include costing of potential threats to the restoration, such as environmental weeds (e.g. perennial grasses or woody weeds), *Phytophthora* dieback and the risk of extremely poor regeneration in any given year.

2 Site preparation and revegetation techniques

2.1 Restoring former pine sites in Australia

The primary challenges associated with the restoration of former pine sites are modified soil conditions, pine wilding invasion, and a lack of native propagules associated with the land use history of areas in which plantations are generally established (Kasel 2004b). The restoration of former pine sites in Australia has generally involved a combination of site preparation measures, wilding control, weed control, and planting and/or sowing of native species, generally eucalypts and a limited range of understorey species (Kasel 2004b).

Kasel (2004a) reviewed a range of projects concerned with re-establishing native species on former pine plantations across Australia. The sizes of the areas ranged from 3 to 1850 hectares and were located in a broad range of areas including: alpine sites in the ACT and NSW; the coastal sands of Jervis Bay Territory; and low and high elevation sites across Victoria. The range of activities associated with each of the restoration projects were generally in the following three areas:

1. Site preparation:
    - Fire (broadcast burn, rough heap and burn, spot burning);
    - Mechanical soil cultivation (chopper roller, ripping, ploughing, mounding, harrowing, bobcat); and
    - Hand spot cultivation (rake hoe, 'Doyle seeder').

2. Revegetation:
    - Seed (hand, helicopter, mechanical, coated, fenced, unfenced); and
    - Plant (unguarded, guarded, tubestock, open-rooted, fenced, unfenced).

3. Pine wilding control:
    - Manual (hand pulling, hand tools, e.g. chainsaws, brush cutters, machetes);
    - Mechanical (scalping, chopper roller);
    - Fire; and
    - Herbicides.

Kasel (2004a) found that the most successful restoration techniques included those that used fire and additionally those situations where the subsequent regenerating vegetation, whether through the soil seed bank or introduced seeds, was of sufficient density to outcompete any regenerating pines. Pine wildings proliferated in areas where fire could not be used, and the successful control of pine wildings remained a major challenge across most sites.

2.2 Options for restoration of former pine sites in the GSS area

Setting clear and achievable goals is essential for restoration projects. To succeed, restoration activities need not only to be based on sound ecological principles and information, but also to be economically possible and practically achievable (Hobbs & Harris 2001). They also have to take their place amongst other options such as providing more resources to protect existing habitats, or doing nothing, which is often the easiest, but not necessarily the most desirable (Hobbs & Harris 2001). In the case of former pine plantations in the GSS area, it is likely that once trees have been harvested the ‘do nothing’ approach would rapidly result in a system dominated by annual weed species that probably has little functional or conservation value. The dominance of weeds and lack of native plant recruitment can be observed at sites throughout the GSS area, including restoration trial plots that have not been seeded and in large, long-cleared areas that were exposed to wildfires in the early and mid-1990s.

Common herbaceous weed species in southwest Western Australia, particularly annual forbs and grasses, are fast growing and easily dispersed (Hobbs 2001; 2003). These species commonly establish after disturbances such as soil turnover, nutrient addition, or fire. Such disturbances are common in harvesting operations in plantations in the GSS area. Native seedling establishment can be prevented or significantly reduced in the presence of annual weed species (Hobbs 2001), which are often more vigorous and compete more effectively for limited soil water and nutrients (Humphries *et al.* 1991). Similar degraded systems have been observed in abandoned farmland in other parts of southwestern Australia.

Native plant recolonization of abandoned farmland in the Western Australian wheatbelt region is also slow to nonexistent, even 45 years after abandonment (Yates & Hobbs 1997; Standish *et al.* 2006; 2008). Old-fields in this region tend to be dominated by non-native annual grasses (Hobbs & Atkins 1991; Yates & Hobbs 1997), which can delay or completely stall the recovery of native vegetation on old fields (Cramer *et al.* 2008). However, limited availability of native propagules has also been found to reduce native species establishment. Standish *et al.* (2007) found that the most compelling reason for the lack of native species recolonization at old-field sites in the wheatbelt was limited seed dispersal. Limited dispersal is predicted to have evolved in the south-west flora in response to natural selection for local persistence in an unchanging landscape (Hopper & Gioia 2004). Standish *et al.* (2007) concluded that in most cases abandoned farmland will not return to native species dominance without assistance. It is also likely that pine harvested sites in the GSS area will remain dominated by annual weeds and not return to native species dominance without assistance.

The degraded system that is likely to result from the ‘do nothing’ approach following the harvesting of pines in the GSS area is not compatible with restoration goals set by the DEC. The Gnangara Park Concept Plan outlines goals for two main types of restoration (CALM 1999): (1) restoration based on the state-of-the-art practice to recreate vegetation that is as close as practical to intact native vegetation in terms of structure and diversity; and (2) less intensive, cost-effective revegetation that aims to create self sustaining communities that support a diversity of fauna and provide linkages and buffers to high value nature conservation areas. Restoration of post-pine harvested sites in the GSS area to an ecosystem that resembles the pre-pine plant community will therefore require active restoration interventions.

2.3 Restoration of *Banksia* woodland communities on the Swan Coastal Plain

Techniques for restoring *Banksia* woodland communities on the sandy soils of the Swan Coastal Plain in the Perth region have been investigated at post-pine harvested sites in the GSS area (Reid *et al.* 2004; Maher *et al.* 2008) and at post-sand mined sites operated by Rocla Quarry Products (Rokich *et al.* 2000, 2002; Turner *et al.* 2006; Rokich & Dixon 2007).

DEC has established restoration trials in the GSS area annually since 2002 using direct seeding across cleared plantation compartments. The aims of these trials are to determine the most successful and cost-effective techniques for revegetating clear-felled pine sites with abundant and diverse native vegetation cover over a broad-scale area. The success of these trials was assessed in 2004 (Reid *et al.* 2004) and 2008 (Maher *et al.* 2008).

Rocla Quarry Products operates five quarries located around Perth, Western Australia, including a 15-ha quarry 30 km northeast of Perth, and a 100-ha site 20 km south of Perth. Prior to the quarry being established the sites were under *Banksia* woodlands on the Bassendean dune system. The company proposes to restore sites after mining with an ecosystem closely resembling the *Banksia* woodland that existed prior to mining (Rokich *et al.* 2000). The reference *Banksia* woodland to be used by Rocla is comparable to the *Banksia* woodlands in the GSS area. Restoration activities at these sites may therefore provide useful information about the success or failure of different site preparation and revegetation techniques. Rocla's northern mine site is located close to pine plantations in the GSS area and research undertaken at this site is particularly relevant. However, there are some limitations to the applicability of research findings between Rocla sites and GSS sites, in particular, soil conditions and the restoration techniques available.

The sand extraction process used by Rocla involves removal of the soil profile to great depths (18–22 m) (Rokich *et al.* 2002), whereas no soil is removed from pine-harvested sites. Pine plantations can also modify soil conditions, associated biota and nutrient cycling processes (Kasel 2004b). Soil abiotic and biotic conditions may therefore vary between post-mined and post-pine areas, even for sites located on the same soil type. Such differences may affect restoration success even if the same site preparation and revegetation techniques are employed.

Rocla's sand mines and restoration sites are located on the Bassendean dune system and the GSS sites are located across both the Bassendean and Spearwood systems. Vegetation community boundaries in the southwest of Western Australia are thought to be controlled largely by soils, landforms and climate (McArthur 1991; Gibson *et al.* 1994). Differences between the soil types and the vegetation communities they support may affect restoration outcomes. However, the Spearwood and Bassendean systems are very similar: they are both composed principally of deep sands, with little structure, and are very infertile (McArthur 1991). Maher *et al.* (2008) found that the vegetation assemblages that established on restoration trial sites in the GSS area did not vary substantially between these two soil types. Site preparation and revegetation techniques carried out on both of these soil types should therefore have similar overall outcomes.

Much of the research undertaken at the Rocla sites has focused on utilizing soil seed banks by translocating topsoil from sites soon to be mined to sites being restored. Research undertaken at Rocla sites has found that the application of *Banksia* woodland topsoil is the most useful, reliable, and economical source of plants, with 77% of perennial seeder species responding to topsoil replacement (Rokich *et al.* 2000, 2002). For some *Banksia* woodland species, topsoil has been found to be the only source of seeds and germinants. However, topsoil application has limitations for species whose seeds are canopy stored and only released following fire or other major disturbances. Seed broadcasting will contribute additional species and substantially increase seedling recruitment. However, studies at the Rocla restoration sites has found that the efficiency of this method is low i.e. 7% of the broadcast mix of diaspores delivered to the site resulted in seedlings (Rokich *et al.* 2002). Topsoil is not available for most of the areas that will be restored in the GSS area; therefore, research carried out at Rocla's restoration sites into broadcast seeds is the most pertinent for restoration in the GSS area.

Research that has been undertaken into different site preparation and revegetation techniques is reviewed in sections 2.4, 2.5, and 2.6. Key findings of relevant studies are outlined and discussed, including the applicability of findings to the restoration of *Banksia* woodland communities in the GSS area. Other issues that have the potential to affect the success of restoration at Gnangara, which have not been investigated to date, are outlined in section 2.7. The outcomes of the studies reviewed form the basis of the recommendations for site preparation and revegetation activities in the GSS area, provided in section 5.1.

2.4 Site preparation techniques

2.4.1 Ploughing, deep-ripping and scarifying

Many restoration operations involve soil cultivation to ease compaction.

Reid *et al.* (2004): plots that were ploughed or deep-ripped recorded the greatest plant abundance and diversity, and there was little difference between these two treatments among sites. Plots that were scarified had the lowest plant abundance and diversity. There were no plots included in the trials that were planted with seedlings and broadcast seed that did not receive any soil treatment. Therefore, the effects of soil treatments could not be compared with the effects of not cultivating the soil prior to seeding. The cost of each treatment was: ploughing $115/ha; deep-ripping: $310/ha; and scarifying $84/ha.

Rokich *et al.* (2000): ripping had no significant effect on seedling recruitment and species richness.

Discussion. Ploughing was an effective and cost efficient method of soil preparation prior to broadcast seeding. Although deep-ripping generated similar results to ploughing, it was the most expensive treatment. Scarifying the soil was the cheapest treatment, but resulted in lower establishment rates for seedlings. Soil treatments would be more efficient if carried out over a larger area and the costs per hectare would therefore be less.

2.4.2 Herbicide

Seedling establishment of many native woody species is significantly reduced in the presence of annual weed species (Hobbs 2001). Weeds commonly establish after disturbance (Hussey *et al.* 1997) and often use the disturbance caused by fire as the opportunity to invade an area (Brown & Brooks 2002).

Maher *et al.* (2008): weed cover negatively affected species establishment and density at restored trial sites. Higher levels of weed cover reduced the percentage of species that establishment and density of some species, in particular *Banksia attenuata* and *Eucalyptus todtiana*. However, weed cover did not reduce the density of all species. Some species therefore appear to be more sensitive to competition from weeds.

Reid *et al.* (2004): the application of herbicide made little difference to plant abundance and diversity at most sites. This is most likely because the trial sites were subject to mechanical disturbance (ploughing, deep-ripping) after the herbicide was applied, burying the sprayed weeds and exposed a fresh source of weed seeds. Alternatively, the boom spraying method used may not have been effective at sites where weed cover was dense. The cost of spraying herbicide was $162/ha.

Discussion. The management and control of weeds will be the biggest challenge for the GSS revegetation program, particularly as the ability to use certain herbicides on the Groundwater Protection Area will be limited (CALM 1999). Weed cover is particularly significant in the long-cleared areas that were exposed to wildfires in the early and mid-1990s. Weed cover negatively affected species establishment and density at the trial sites. Spraying with non-residual herbicide produced variable results; however, the effectiveness of this treatment was most likely compromised by the disturbance of soil (ploughing, deep-ripping) after the herbicide was applied. Spraying herbicide was a relatively inexpensive treatment and is likely to benefit the establishment of native species if the application method and timing is modified (i.e. after mechanical disturbance and burning, prior to broadcast seeding).

2.4.3 Burning

Immediate post-fire environments generally favour seedling establishment due to the ‘ash-bed effect’, which sterilises the soil through heat, removes growth-inhibiting chemicals and microbes, changes the soil microflora and provides a flush of nutrients, and is commonly recorded in Australian forest systems (Gill 1979; Khanna & Raison 1986; Chambers & Attiwill 1994; Cummings *et al.* 2007).

Reid *et al.* (2004): burning produced variable results among the sites, which is not surprising considering that the application of this treatment also varied among sites. Some sites were burnt twice, once by wildfire and then again prior to the restoration trial being established. The sites had different fuel loads and subsequently burned at different fire intensities. The cost of burning was $964/ha.

Maher *et al.* (2008): burning the seedbed prior to broadcasting did not increase the number of species that established or the density of plants at the trials sites.

Discussion. Burning produced variable results in the trials. This may be due to a time lag between burning and seeding, which means that seeds were not exposed to the ash-bed effect. Although this treatment is relatively expensive compared with soil cultivation techniques, burning remains a favourable method to use in restoration activities as it is an operationally efficient way to remove logging slash from a site. In addition, fire can kill pine seed and pine wildings thereby limiting the need to use intensive manual methods that require a high and ongoing input of resources, or herbicides that may be undesirable due to their adverse effects on the environment including water quality and native species (Kasel 2004a). Fire also removes the thick litter layer that often accumulates on the floor of pine plantations and remains after harvesting. Pine litter would act as a mulch layer, which has a negative effect on recruitment of *Banksia* woodland seedlings from topsoil or broadcast seeds (Rokich *et al.* 2002). The creation of ash-bed conditions at GSS sites is therefore a secondary benefit of burning. It is highly likely that the application of smoke agents such as butenolide to topsoil or broadcast seed would be a more efficient way to stimulate germination of species that require smoke, but of course would not provide the other benefits just mentioned.

2.4.4 Harrowing/raking

It is assumed that the low efficiency rates of broadcast seed in post-mining rehabilitation is related to a number of factors, of which seed predation and wind and water erosion are likely to be the most important (Turner *et al.* 2006). Burial of seeds (through raking/harrowing) generally ensures that seeds are less prone to loss or displacement via these processes (Rokich & Dixon 2007). Additionally, Bell *et al.* (1995) documented that seed burial generally ensures greater and consistent levels of soil moisture availability and, hence, improves chances of seedling survival, particularly in systems where rainfall can be light and intermittent.

Reid *et al.* (2004): harrowing the soil to cover the seeds after sowing to a depth of approximately 5 cm had little effect on plant abundance and diversity. However, the number of sites where this treatment was tested was limited.

Turner *et al.* (2006): topsoil raking with a hand-cultivator to an average depth of 5–10 mm, once the seeds had been broadcast, significantly improved seedling emergence under in situ conditions. The seed mix included eleven native *Banksia* woodland species selected to represent dominant local species, which possessed varying seed syndromes, seed sizes, seed appendages, and life forms.

Discussion. One of the most significant factors in emergence of seedlings is the burial of propagules and seeds. Harrowing the soil to cover the seeds after sowing had little effect on plant establishment in the DEC trials, and was therefore considered unnecessary (Reid *et al.* 2004). However, Turner *et al.* (2006) found that topsoil raking to an average depth of 5–10 mm following sowing proved an effective treatment for substantially increasing emergence and has the benefit of being low cost and relatively straightforward to implement.

The depth of soil cover over the broadcast seeds in the DEC trials (50 mm) was most likely too great to enhance seedling establishment, particularly for small-seeded species (< 2 mg). The effect of seed size on depth of burial and subsequent emergence has been well documented. Generally, the larger the seed the greater the seedling’s capacity to emerge from deeper locations (van der Valk 1974; Maun & Lapierre 1986; Grant *et al.* 1996).

Grant *et al*. (1996) showed that most jarrah forest species were unable to emerge from depths greater than 2 cm. Rokich *et al.* (2000) found the optimal depth for seedling emergence of *Banskia* woodland species was 1 cm, with increased burial depth beyond this point resulting in a negative relationship with seedling emergence. Many species (e.g., *Eremaea pauciflora*, *Kunzea ericifolia*, *Melaleuca trichophylla*, and *Pericalymma elliptica*) were negatively affected even by a small increase in depth of burial to 2 cm (Rokich *et al.* 2000). All of these species belong to the Myrtaceae, and all have relatively small to fine seeds. The only species to emerge from 5 cm depth or more were legume species which, under natural conditions, often utilize eliasomes to promote burial of seeds by ants (Rokich *et al.* 2000).

Harrowing or raking the soil over broadcast seeds to depths shallower than that used in the DEC trials may have a more beneficial effect on seedling emergence. However, the operational feasibility of cultivating large areas to a depth of 5–10 mm is unknown. If the soil cannot be raked over seeds to shallow depths on a broadacre basis, this practise is not recommended for restoration at GSS sites.

2.4.5 Fencing

Reid *et al.* (2004): fencing had a slight negative effect on plant abundance and diversity. This may be a consequence of poor fence design i.e. the fence might have been ineffective at keeping kangaroos out and once inside the fence the kangaroos spent longer periods within the contained areas. Alternatively, grazing of weeds may have been higher outside the fenced plots, benefiting growth and survival of native species through reduced competition. The cost of fencing was $1900/ha.

Discussion. Fencing was one of the least effective and most expensive treatments and the cost of fencing is likely to be prohibitive over large areas. However, browsing and grazing by kangaroos and emus appears to continue to affect restoration trials.

2.4.6 Mulch and other soil-stabiliser applications

Sites that have been mined for sand are subject to wind erosion that may lead to sand and seed displacement, and lower plant survival levels (Rokich *et al.* 2002). Topsoil stabilisers such as polymer gels, jute-matting, mulch/vegetative matter, and papier-mâché act as barriers to erosion.

Rokich *et al.* (2002): a mulch of the canopy material from adjacent native vegetation was made using a large-scale mulcher and was applied at two thicknesses (5 and 10 mm) and seeds were broadcast over and under the mulch. In all treatments, mulch had a negative effect of on recruitment of seedlings resulting from topsoil and broadcast seeds.

Rokich and Dixon (2007): papier-mâché and brush material inhibited seedling recruitment by 50%, and a thin biodegradable polymer gel had no affect on seedling recruitment. However, after the fourth growing season, plant survival and growth were higher under all three topsoil-stabiliser treatments, indicating a longer term positive effect of soil stabilisers on plant survival.

Discussion. Mulch inhibited the seedling recruitment and species richness of topsoil and broadcast species. For achieving effective restoration of *Banksia* woodland species, mulch therefore does not provide sufficient benefits to justify the significant costs associated with harvesting and distribution. The application of papier-mâché and brush material inhibited seedling recruitment and a thin biodegradable polymer gel had no effect on recruitment. Although the polymer gel had a positive effect on plant survival and growth in the longer term, the additional cost of this treatment over large areas is likely to be prohibitive.

2.4.7 Fertiliser

Rokich and Dixon (2007): observations of a post-sand extracted site undergoing restoration to *Banksia* woodland suggested that fertiliser application alone produced the most favourable seedling survival response. At a former tip site restored to *Banksia* woodland within the urban-bushland setting of Kings Park, plants of certain species under a fertiliser treatment performed better than plants under the control. Similarly, within the urban bushland of Bold Park, fertiliser additions increased survival of 50% of the species tested.

Discussion. Observations suggest that fertiliser application benefits plant survival and overall plant development within *Banksia* woodland restoration. However, this treatment requires further investigation particularly for proteaceous species that are sensitive to phosphorus (Lambers *et al.* 2007).

2.5 Seed treatments

2.5.1 Smoke (aerosol, water, and butenolide)

Rokich *et al.* (2002): aerosol smoke significantly increased total seedling recruitment from the soil seedbank by 3.6-fold and species richness by 1.4-fold. Fourteen species showed significantly higher recruitment with aerosol smoke treatment compared with the control. Another 13 species showed non-significant higher recruitment with aerosol smoke treatment. The application of smoke water generally did not increase the number of species that emerged from the soil seedbank. Only one treatment (DC10 at the highest rate) significantly increased seedling recruitment, but was only 50% of that achieved with aerosol smoke. For six species, the levels of recruitment were significantly increased by increasing application rates of the smoke water agents.

Rokich *et al.* (2002): the application of aerosol smoke to broadcast seeds significantly increased germination of *Banksia attenuata*, *Hovea trisperma* and *Xanthorrhoea preissii*, decreased germination of *Banksia menziesii*, and did not have an effect on the remaining nine species compared with the germination of these species in plots where aerosol smoke was not applied.

Rokich and Dixon (2007): the discovery of a butenolide has prompted a re-evaluation of smoke as a cue for germination. The butenolide (in smoke) is capable of stimulating germination to the same or greater extent than aerosol smoke and is not phytotoxic to seeds under periods of prolonged exposure or at concentrations many times higher than the optimum required for germination (Flematti *et al.* 2001; Flematti *et al.* 2004b; Flematti *et al.* 2004a; Merritt *et al.* 2006). Under field conditions, application of butenolide has great advantages over application of aerosol smoke or smoke water. Butenolide is likely to be effective at an application rate of 1–20 g of active ingredient per hectare. These application levels are easily applied for broad-scale restoration activities (Flematti *et al.* 2005).

Discussion. Recruitment of some *Banksia* woodland species is enhanced by the exposure of broadcast seeds to smoke products. Exposure to butenolide is likely to be equally effective at stimulating germination of these species, but this has not been tested.

Exposure of the topsoil seedbank to aerosol smoke enhances total seedling recruitment and species richness. However, this method is not practical for broad-scale restoration because of difficulties in application. Smoke water application is more practical but is not as effective in stimulating seedling recruitment as aerosol smoke. Butenolide is capable of stimulating germination to the same or greater extent than aerosol smoke (Rokich & Dixon 2007). It is feasible to produce butenolide in commercial-scale quantities and it is easily applied for broad-scale restoration activities (Rokich & Dixon 2007). However, the effects of this product on soil seedbanks from *Banksia* woodlands have not been tested.

2.5.2 Seed coating

Seed coating, or seed pelleting, is a process whereby seeds are covered with filler materials and binders that facilitate mechanical dispersal. Seed coatings are widely used in horticulture to allow precision seed sowing and optimal seedling emergence.

Turner *et al.* (2006): coating improved seedling emergence under in situ conditions. For individual species, coating significantly improved the percentage of seeds emerging for two species, *Gompholobium tomentosum* and *Regelia ciliata*. Four additional species (*Allocasuarina fraseriana*, *Anigozanthos manglesii*, *Melaleuca scabra*, and *Nemcia capitata*) emerged at higher rates when coated, but this was not statistically significant. Higher emergence percentages were recorded for the non-coated *Banksia attenuata* and *B. menziesii* seeds than the coated *Banksia* seeds, though this was not significant for either species. Further research is being conducted into incorporating treatments, such as smoke, into the coatings.

Discussion. Polymer seed coatings increased seedling emergence rates in *Banksia* woodland restoration sites by 17–55%, which may due to decreased seed predation and/or erosion (Turner *et al.* 2006). Such seed coatings may be a practical and beneficial technology as a means to improve seedling recruitment from native seeds. However, the key question is whether this increase in emergence offsets the additional cost of seed coating, and whether it is cheaper (or possible) to purchase more seeds.

2.5.3 Time of sowing

Germination in native species from the southwest of Western Australia generally occurs during winter (June–August), when water is available and temperatures rarely exceed 20 °C (Bell *et al.* 1995).

Turner *et al.* (2006): sowing (non-coated) seeds earlier in the growing season in late-autumn rather than mid-winter (i.e. May rather than July), improved seedling-recruitment levels 12-fold. Overall fewer seedlings emerged from July sowings, compared to May sowings for all species except *Acacia pulchella*. In four species, *Allocasuarina fraseriana*, *Anigozanthos manglesii*, *Kunzea ericifolia*, and *Regelia ciliata*, this difference was statistically significant.

Maher *et al.* (2008): substantial differences in rainfall occurred over a range of time periods (30 days, 60 days, 90 days, one and two years after sowing) at the GSS trial sites, but these did not effect the vegetation assemblages that established. These results were also evident in the large variation in success and density of establishment among sites that were seeded in the same year using the same seed mix.

Discussion. Seedling emergence following seed broadcasting may be maximised by sowing coated seeds earlier in the growing season i.e. May rather than July (Turner *et al.* 2006). The difference between May and July sowings may reflect the particular conditions during the experimental year (i.e. the amount of rain that fell directly after sowing), rather than a long-term trend of generally higher germination rates following sowing in May. Maher *et al.* (2008) found that differences in rainfall after broadcasting did not appear to affect the establishment and density of the restored vegetation, and there did not appear to be a threshold of minimum rainfall required for establishment. Site factors instead appear to have a greater impact on species establishment in the GSS area. However, Rokich *et al.* (2000) demonstrated that winter and spring sowing times depressed seedling recruitment from the topsoil, compared with autumn sowing times. Similarly, Roche *et al.* (1998) demonstrated that autumn smoke application to topsoil within *Banksia* woodland resulted in better seedling recruitment than winter or spring smoke application. The optimal timing of sowing therefore remains largely unresolved. However, since negative effects on plant recruitment have been recorded for sowing seeds in June and no negative effects have been recorded for sowing seeds in May, in the absence of additional trials, seed should be sown at restoration sites in May.

2.6 Topsoil treatments

2.6.1 Screening

Soil screening is employed to remove larger soil and vegetative matter during the mining process. This process results in concentration of seeds in the topsoil seedbank.

Rokich and Dixon (2007): only 48% of the typical seedling recruitment occurred following spread of the screened topsoil seedbank. It was determined that 28% of the topsoil seedbank was removed during the topsoil screening operation. The remaining topsoil seedbank (24%) was possibly lost after the screened topsoil was spread, most likely through wind erosion. Small-seeded (<1 mg) species were most negatively affected by topsoil screening.

Discussion. Seedling recruitment was significantly lower from the screened topsoil seedbank a post-mined site undergoing restoration to *Banksia* woodland. Small-seeded species were most negatively affected by topsoil screening. Such species may be more prone to wind erosion. Topsoil screening is therefore not recommended for *Banksia* woodland restoration.

2.6.2 Depth of stripping

Rokich *et al.* (2000): fresh topsoil that was stripped to a depth of 10 cm and re-spread to the same depth exhibited average seedling recruitment levels of 254 seedlings per 5 m^2 with a mean richness of 22 species. Soil stripped to 30 cm and re-spread to a depth of 10 cm showed a lower density of seedlings and species richness.

Discussion. The *Banksia* woodland seedbank is concentrated in the relatively shallow upper topsoil with 92% of seeds in 10 cm of topsoil occurring in the upper 5 cm. Removal of the top 5 cm of topsoil is therefore more likely to be successful in *Banksia* woodland restoration. A dilution effect of adding the 5–10 cm layer will result in almost halving the total recruitment of soil-buried seeds. Operationally, however, methods stripping the top 5 cm or less of topsoil may be difficult to implement on a broadacre basis.

2.6.3 Depth of spread

Rokich *et al.* (2000): optimal depth of seed burial was 1 cm, followed by 2 cm, with a significant decline in emergence at 5 cm and 10 cm.

Discussion. The topsoil replacement depth is driven by the capacity of seeds to emerge (see discussion in section 2.4.4: harrowing/raking). With most of the *Banksia* woodland seedbank occurring in the top 5 cm of soil, it is not surprising that seedling emergence is negatively affected by the greater depths of seed burial (Rokich *et al.* 2000). Most jarrah forest species cannot emerge from depths greater than 2cm (Tacey & Glossop 1980; Grant *et al.* 1996). Both of these studies concluded that utilizing the majority of the topsoil seed reserve could be made if topsoil were spread on to restoration sites at depths of less than 5 cm. Rokich *et al.* (2000) further added that the depth of spread would need to be operationally feasible on a broadacre basis, and that for Rocla's *Banksia* woodland restoration sites this depth is 10 cm. However, the authors acknowledged that considering few species emerged from 5 cm depth or more in their trials, even 5 cm depth is not optimizing the seed storage capacity of topsoil.

2.6.4 Seasonal timing of stripping and spreading

Rokich *et al.* (2000): topsoil was stripped when it was dry (autumn) and stripped when it was wet (winter). Average seedling recruitment following an immediate spread of an autumn topsoil strip was 73 seedlings per 5 m^2 represented by 18 species. Following an immediate spread of a winter strip there were 5 seedlings per 5 m^2 represented by an average of three species. Following a 3-month stockpile period there was no seedling recruitment in either topsoil strip.

Discussion. Winter and spring topsoil-replacement operations depressed seedling recruitment from the topsoil, compared with autumn operations. Spreading topsoil in the middle of winter or spring may not provide seeds with sufficient time for germination and establishment.

2.6.5 Stockpiling

Rokich *et al.* (2000): average seedling recruitment in fresh (i.e., direct return) topsoil from an autumn topsoil strip was 131 seedlings per 5 m^2. The 1-year-old and 3-year-old topsoil showed a substantial and significant decline in the total number of seedlings (to 55% and 34%) and a significant decline in species richness (to 78% and 61%). Twenty-eight species from a total of 61 species in the trial showed significantly higher seedling recruitment in fresh topsoil compared with the stockpiled topsoils. Different grass species formed different cover crops depending on the length of topsoil stockpiling. A fire ephemeral, *Austrostipa compressa*, recruited only in fresh topsoil. Meanwhile, a pervasive weedy grass, *Ehrharta calycina* (perennial veldt grass), recruited in 1-year-old topsoil and at a significantly higher density in 3-year-old topsoil.

Discussion. Stockpiling topsoil, for even short periods, substantially decreases seedling recruitment and species richness of native species. This may be attributed to decomposition of seed or triggered germination when seed is exposed to the elevated moisture and temperature conditions within the stockpile (Rokich *et al.* 2000). Stockpiles appear to accumulate wind-blown seeds of *Ehrharta calycina*, possibly because they are prominent features in the otherwise flat landscape.

2.7 Other considerations for restoration activities in the GSS area

2.7.1 Altered ecosystem processes

Altered soil chemical properties are infrequently investigated in restoration projects involving former pine plantations in Australia despite the fact that they are often invoked as barriers to restoration of native species. Soil cultivation has primarily been undertaken to improve soil physical properties to reduce compaction and erosion and improve water infiltration (Kasel 2004a). However, pine plantations have been found to modify soil conditions, associated biota and nutrient cycling processes (Kasel 2004b).

A meta-analysis of changes in soil carbon stocks with land use conversions, including 74 studies worldwide, found that soil carbon stocks declined by 15% after land use change from native forest to conifer plantations (Guo & Gifford 2002). However, plantation age also had significant effects on the soil carbon stocks following land use changes. Carbon stocks were reduced by 20% when the plantations were less than 40 years old, but were restored to the original levels in plantation more than 40 years old. While of current interest given the growing market for carbon, changes in soil carbon levels per se are unlikely to affect the potential for restoration.

Turner and Lambert (1988; 2000) reviewed a range of studies from Australia and New Zealand that compared soils under relatively mature conifer plantations (more than 20 years of age) with soils beneath adjacent native vegetation. The quantity of carbon in the soil was generally related to the soil nutritional status, and levels were generally lower under the plantations than under the original native vegetation. The effects of pines on soils were quite variable could not be attributed to a single cause, and represent the combined results of clearing, site preparation, competition control, planting and subsequent management such as thinning. Importantly though, the differences between soils (including pH and nutrients) under plantations and those under prior vegetation were minimal in soils with lower nutrient status such as siliceous sands.

A widely cited effect of pine litter is to increase the acidity of soils. The acidifying effect of pine forests is primarily caused by the disruption of nutrient cycles (particularly nitrogen, sulphur, and the base cations) by vegetation changes and forest management practices, and the leaching of organic acids generated in slowly decomposing pine litter (Scholes & Nowicki 1998). Numerous historical studies have demonstrated significant increases in the pH and base status of topsoil as a result of forestry; however, results obtained from these studies the have been highly variable (Scholes & Nowicki 1998). This variability stems from a number of factors, including differences in tree species, climate, topography, parent material and pre-afforestation acidity status.

Kasel (2004b) investigated the effects of land use change on soil chemical properties within mature pine forests and adjacent native forests within the Delatite Arm Reserve (Victoria), Namadgi National Park (ACT) and Kosciuszko National Park (NSW), and found significant differences between these land types. Significantly, trends varied according to location with pH, total C and N in pine plantation at the Delatite Arm Reserve greater than that in the adjacent native forest, with opposite trends at Namadgi and Kosciuszko National Parks with absolute values ranging widely according to location. These results again highlight the importance of site specific factors and plantation management and harvesting practices in affecting soil properties and nutrient cycling processes.

Although pine plantations can modify soil conditions, their impacts are not commonly investigated in restoration projects involving former pine sites in Australia, and have not been investigated in the GSS area. The effects of numerous treatments have been investigated in the GSS area, including ploughing, deep-ripping, harrowing, spraying, and burning. However, plant recruitment has consistently varied among individual trial sites. Maher *et al.* (2008) suggested that this may be due to differences in factors such as soil physical and chemical properties among individual sites. Such variations may occur naturally and/or there may be residual effects of the pine plantations formerly located on the sites. However, the extent to which soil properties may have been altered, and the effects that such alterations may be having on restoration trials, is unknown. It may be necessary to address the altered ecosystem processes before plant species and community structure can be reliably restored.

2.7.2 Post-pine harvested sites with established understorey vegetation

The site preparation and seed treatments for restoration activities outlined in sections 2.4–2.6 generally assumes the native vegetation at the sites being restored has been cleared in its entirety through mining or pine-harvesting operations. However, native vegetation still persists within some pine compartments as well as areas where pine has been cleared in the GSS area.

Several studies have been undertaken to identify the extent and condition of the native overstorey and understorey in pine compartments in the three plantations within the GSS area: Gnangara, Pinjar and Yanchep. Areas of persistent native vegetation present underneath pines within the southeastern half of the Gnangara sub-area have been mapped in detail (Woodman Consulting 2005, 2008). Each pine compartment was surveyed for native flora, a list of species for each area generated, and cover values for native understorey and overstorey were visually estimated. Native vegetation cover in pine compartments within proposed ecological linkages in the remaining areas of the Gnangara, West Gnangara and West Pinjar sub-areas were visually estimated and mapped by DEC staff in July-November 2008 (Brown *et al.* 2009). Native vegetation cover in the East Yanchep sub-area is currently being evaluated by Woodman Environmental Consulting (Brown *et al.* 2009). Transect-based studies of native understorey density have indicated that the native vegetation in East Yanchep is diverse, dense and still widespread (DEC 2002).

Of the 7364 ha of pine plantation that has been assessed for native understorey and overstorey, 3152 ha (43%) had vegetation cover greater than 10% (either understorey or overstorey) (Brown *et al.* 2009). West Gnangara had the highest percentage (66%) of plantation with native vegetation cover greater than 10%, followed by West Pinjar

(50%), and the Gnangara subarea had the lowest percentage (26%). It is expected that East Yanchep will be similar to Pinjar and West Gnangara in terms of its persistent native vegetation.

There is some uncertainty about the restoration techniques most applicable to areas with persistent native vegetation understorey and/or overstorey, which have not yet been harvested for pines. There has been some suggestion that the methods for restoration of these areas may vary from areas with no persistent vegetation, i.e. that restoration effort may be lower in areas with persistent vegetation. However, pine harvesting will destroy or disturb much of the native vegetation, particularly with increased levels of vegetation removal (e.g. tree stumps and branches) that will occur with the development of a new bioenergy plant north of Perth, which will utilise plantation residue. Also, further disturbance (or removal) of native vegetation is likely to occur through burning.

Fire is necessary to minimise pine wilding regeneration, which has been found to be prolific at sites where fire has not been used (Kasel 2004a). Fire is also required to remove accumulated litter beneath the pine trees, which is likely to prevent the establishment of native species. In studies of *Pinus radiata* plantations, there was no indication of the surface litter being incorporated into the soil over an 18 year period of time (Turner & Lambert 2000). As mulch has a negative effect on seedling recruitment in *Banksia* woodland (Rokich *et al.* 2002), the litter layer present after pine harvesting will probably need to be removed for native plants to establish. The easiest and most effective way to remove pine litter and seed is through burning the site, which will also remove the native vegetation.

Due to high levels of disturbance during harvesting, and the need to use fire to kill pine seed and remove pine litter, the techniques used in restoring sites with persistent native vegetation will therefore need to be similar to sites without native vegetation. After restoration activities have been carried out, greater numbers of species and/or seedlings may recruit at sites with persistent native vegetation if seed remains in the soil after pine harvesting.

In addition to pine compartments with persistent native vegetation, there are also former pine compartments in the GSS area that were cleared years ago, will not require harvesting, and have persistent native vegetation (Brown *et al.* 2009). There is also some uncertainty about the restoration techniques most applicable to these areas. Restoration treatments for such areas should be based on an assessment of the current state of the compartment (see Woodman Consulting 2005, 2008). Compartments with satisfactory levels of native vegetation cover (i.e. if vegetation cover is mostly native, even if only a few species) could be retained as is, at least in the short term. If there are pine wildlings and/or problem weed species in the compartment, these need to be removed or treated. If DEC decides that species diversity needs to be increased or that a compartment has unsatisfactory levels of cover, a full suite of restoration efforts need to be considered. This may require the compartment to be burned and treated as for other restoration sites.

3 Species lists and requirements

To restore post-pine harvested sites in the GSS area with an ecosystem that resembles the pre-pine plant community the species included in revegetation activities will need to reflect the species present in the surrounding areas of *Banksia* woodland. *Banksia* woodlands are floristically rich and taxonomically diverse (Dodd & Griffin 1989). *Banksia attenuata* and *B. menziesii* dominate the overstorey, while *Eucalyptus todtiana*, *E. gomphocephala*, *E. marginata*, *Allocasuarina fraseriana*, *Nuytsia floribunda* and other *Banksia* species occur less frequently. The understorey is represented by the dominant woody families Proteaceae, Myrtaceae, Papilionaceae, and Epacridaceae, and nonwoody understorey families Orchidaceae, Cyperaceae, Restionaceae, Haemodoraceae, and Anthericaceae (Beard 1989; Dodd & Griffin 1989).

The species lists developed for the revegetation of post-pine harvested sites to *Banksia* woodland will need to take into account:

- Two types of restoration (defined for the purposes of this report as): a higher (80%) and lower (50%) level of species return;
- Two soil types: the Bassendean and Spearwood systems;
- Different topographical locations: upper and mid-dune slopes, low-lying (or dampland) areas and seasonal wetlands;
- A structure that will be representative of the vegetation community where limited numbers of species are returned; and
- Specific species that are required as habitat for fauna e.g. Carnaby's Black-Cockatoo.

Ideally these species lists would also include the following information:

- The density of established vegetation desired for each species;
- The approximate quantities of seeds required to achieve the desired density; and
- Notes on the requirements of species likely to have poor establishment rates through direct seeding.

However, due to the limitations of the surveys conducted and information available (see section 3.1), not all of these parameters could be provided (see recommendations in section 5.2).

3.1 Surveys

Several surveys of remnant vegetation have been undertaken that incorporate sites in the GSS region. These include surveys of remnant vegetation located within the GSS area (Woodman Consulting 2005, 2008), in surrounding areas on the Gnangara groundwater system (Mattiske Consulting 2003, DEC floristic plots), and broader surveys across the Swan Coastal Plain (Gibson *et al.* 1994). These studies are described below.

3.1.1 Woodman Consulting (2005; 2008)

Surveys of intact remnant native vegetation areas located both within and between pine compartments, and within undisturbed native bushland were carried out within the southeastern half of Gnangara in 2003 and 2005 (Woodman Consulting 2005, 2008). Intact remnant native vegetation areas were mapped using a combination of cadastral boundaries and digital aerial photography at a scale of 1:10 000. All plant community boundaries were verified on foot. Detailed site assessments were conducted within each plant community, with the following information collected at each site:

- GPS location
- Topography
- Soil type
- Fire history
- Percentage foliage cover of each native species present
- Presence of weed species

Plant community descriptions follow the methods used to survey the 'Bush Forever' sites (Government of Western Australia 2000).

The survey areas were located on the Bassendean Dune system. The dominant vegetation in this area is *Banksia* woodland; however swamps may be present in dune swales (Beard 1990). The surveyed area is predominantly located on the Bassendean Complex–North as described by Heddle *et al*. (1980): vegetation ranging from low open forest and low woodland of *Banksia* species – *E. todtiana* to low woodland of *Melaleuca* species, and sedgelands on moister sites.

A total of 126 native plant taxa were recorded within areas of remnant native vegetation in the 2003 survey. These represented 28 families and 75 genera, with the most well-represented families being Myrtaceae (26 native taxa), Papilionaceae (13 native taxa) and Proteaceae (12 native taxa). A total of 17 woodland communities (12 dominated by *Banksia* species and 5 dominated by *Melaleuca preissiana*) were mapped.

A total of 158 native plant taxa were recorded within areas of remnant native vegetation in the 2005 survey. These represented 43 families and 129 genera, with the most well-represented families again being Myrtaceae (28 native taxa), Papilionaceae (14 native taxa) and Proteaceae (13 native taxa). A total of two forest (one *Banksia* dominated and one *Melaleuca* dominated), nine woodland (seven located in swamps and low lying areas and two on slopes with grey sands) communities were mapped.

While the surveys of remnant vegetation within the GSS area provides valuable information about species present in the area, species lists for restoration cannot be accurately derived from this source alone. This is primarily because the remaining vegetation doesn't necessarily represent the vegetation that was present in the areas where pines are located now. Most of the remaining plant communities occur on low-lying areas, which were originally too wet to plant to pine, or other sites that were considered unsuitable for pines due to the nature of the soil and topography. Species lists based only on surveys of remnant vegetation within the GSS area are therefore at risk of containing a high proportion of species that prefer damper conditions. Such species may not establish as successfully on the higher dune slopes where most pine compartments, and thus restoration sites, are located. Species lists for restoration in the GSS area should therefore include species that occur in vegetation communities that are located on similar soils and topographical locations in bushland areas in the broader region surrounding the GSS area.

3.1.2 Gibson et al. (1994)

A survey of the plant communities of remnant bushland on the southern Swan Coastal Plain was undertaken to provide more detailed knowledge of the conservation status of species and communities that occur in this area. Five hundred and nine sites (10 m × 10 m quadrats, plots) were established and within each site all vascular plants were recorded, and data on slope, aspect, vegetation structure and condition was collected. The floristic data were classified according to similarities in species composition to define the major regional community types.

The floristic analysis defined 30 community types. Some of these groups were further subdivided, giving a total of 43 types and subtypes. Of the 30 major community types, three are found on the heavy soils of the eastern coastal plain, 16 in seasonal wetlands, four are centred in the Bassendean Dunes and seven are largely restricted to Spearwood and Quindalup systems. A description of each community type and subtype was provided; species that were found in 50–80% of plots were listed as common and species that were found in >80% of plots were listed as typical.

3.1.3 Mattiske Consulting (2003)

Mattiske Consulting (2003) integrated data on flora and vegetation on the Gnangara groundwater system utilising previous studies in the area. This included previous studies by Griffin (1994), Gibson *et al.* (1994), Keighery (1996) and the Department of Environmental Protection (1996). A total of 193 sites were included from these studies, with each site consisting of a 10 m × 10 m quadrat. A further 298 additional sites (10 m × 10 m quadrat) were established and recorded in the spring months of 2001, 2002 and 2003 on sites not covered by previous studies. A total of 491 sites were therefore established and recorded by the various authors.

A total of 963 vascular plant taxa from 91 plant families and 344 genera were recorded within the project area and incorporates previous data. Of these, 124 taxa were introduced plant taxa. The method of site-vegetation typing as defined by Havel (1968) for the plant species and plant communities on the Bassendean and Spearwood dune systems for the northern Swan Coastal Plain was used to categorise the various vegetation communities that were surveyed on the Gnangara groundwater system. A total of 32 site-vegetation types were defined for the area.

While the database of these data (Mattiske Consulting 2003) is a valuable resource, it could not be accessed to use in the development of seed lists for restoration in the GSS area. A hard copy of the report is available, which includes a list of species recorded within each site. However the report does not provide a list of species typical and common to each community type or a list of which plots occur within each community type. Therefore relevant plots could not be identified, and the data entered by hand to determine typical and common species within the communities of interest. If this data becomes available it should be used to refine the species lists provided in this report.

3.1.4 DEC floristic plots in the GSS area

The DEC undertook a floristic survey at around 50 sites, each consisting of 10 × 10 m quadrats in areas of bushland around the GSS area. While the plots have been surveyed, species identification is only partially complete. Therefore, these data were not a reliable source to include in the development of seed lists for restoration in the

GSS area at this stage. When the species lists have been completed, these data should be integrated with the Mattiske Consulting (2003) database and used to refine the species lists provided in this report.

3.2 Development of species lists for different vegetation communities

3.2.1 Communities on the Bassendean system

The Bassendean system consists of low gently undulating dunes, and the swales tend to be swampy (Beard 1990). Three species lists were developed for this system: Dry *Banksia* Woodland (mid and upper dune slopes); Damp *Banksia* Woodland (low-lying areas that are likely to be seasonally waterlogged); and Seasonal Wetland.

Banksia community types and subtypes centred on the Bassendean system identified by Gibson *et al.* (1994) include 20a-b, 21a-c, 22, and 23a-b. All communities surveyed by Woodman Consulting (2005; 2008) were assigned a corresponding community type identified by Gibson *et al.* (1994). The types that occurred within the GSS area included 21c, 22, 23a and 23b (Woodman Consulting 2005, 2008). Species lists from these communities were used to develop seed lists for restoration in the GSS area. Other communities on the Bassendean system identified by Gibson *et al.* (1994) were not included in the species lists for the GSS area because they occurred beyond the region, or they occurred within the region but were located on a different soil type.

Community types and subtypes of the seasonal wetlands identified by Gibson *et al.* (1994) include 4–9, 10a, 10b, and 11–19. Community types that were identified as occurring within the GSS area (Woodman Consulting 2005, 2008) include 4, 11, and 12, and species lists from these communities were used to develop seed lists for restoration in the GSS area. Other seasonal wetland communities identified by Gibson *et al.* (1994) were not included in the species lists for the GSS area because they occurred well beyond the GSS region or were restricted to other soil systems.

Species recorded in the Forest and Woodland plant communities identified by Woodman Consulting (2005; 2008) were entered into a spreadsheet. Species lists for community types that were replicated between the two reports were combined (W4, W14, W15, and W16). The typical and common species of the relevant Gibson *et al.* (1994) community types (21c, 22, 23a and 23b) were included in the spreadsheet. Communities were divided into two ‘supergroups’ identified by Gibson *et al.* (1994). These were Group 2: the seasonal wetland group (community types 4, 11 and 12); and Group 3: largely centred on the Bassendean Dunes (community types 21c, 22, 23a and 23b). Group 3 was separated into two subgroups: Dry *Banksia* Woodlands, which are located on drier midslopes (community types 23a and 23b); and Damp *Banksia* Woodlands, which are located in low lying areas that are likely to be seasonally waterlogged (community types 21c and 22). The total number of species in each group was: 150 in Dry *Banksia* Woodland; 111 in Damp *Banksia* Woodland; and 86 in Seasonal Wetlands.

To achieve species richness levels similar to intact communities the levels for each restored community (from Gibson *et al.* 1994 community types) should be approximately 58 species for Dry *Banksia* Woodland [mean richness of communities

23a (62.8) and 23b (53.8)]; 37 species for Damp *Banksia* Woodland [mean richness of communities 21c (40.5) and 22 (32.5)]; and 30 species for Seasonal Wetlands [mean richness of communities 4 (36.9), 11 (27.2), and 12 (26.4)].

All species included in the Gibson *et al.* (1994) communities were retained in the species list, whether they occurred within the Woodman Consulting (2005; 2008) surveys or not. This was to counteract the large proportion of sites surveyed in the GSS area that occur on low areas that were originally too wet to plant to pine or were unsuitable due to the nature of the soil and topography. Inclusion of species in the Gibson *et al.* (1994) communities should ensure that the species lists for the GSS area do not contain an over-representation of species that prefer damper conditions.

Species that occurred in less than four Dry *Banksia* Woodland communities, in less than two Damp *Banksia* Woodland communities, and in less than three Seasonal Wetland communities (Woodman Consulting 2005, 2008) were removed from the species list. After these species were removed, the total number of species on each list was 73 for Dry *Banksia* Woodland; 57 for Damp *Banksia* Woodland; and 45 for Seasonal Wetlands. The cut-off limit for removing species from each system varied according to the number of species present in the initial list and was aimed to include around 15 to 20 more species than would be likely to occur in intact communities. It is likely that for a number of the species included in these lists to sourcing seeds will be difficult, or they will be difficult to establish in restored sites for a range of reasons; such 'recalcitrant' species feature prominently in the restoration of south-western Australian ecosystems. Additional species were therefore included in the species lists to offset the likely problems associated with establishing such species.

3.2.2 Communities on the Spearwood system

Woodman Consulting (2005; 2008) did not survey any communities on the Spearwood system; therefore, only data from Gibson *et al.* (1994) were available to develop species lists for the GSS area. The only *Banksia* woodland community centred on the Spearwood system identified by Gibson *et al.* (1994) was type 28. The Spearwood Dunes are generally higher and steeper than the Bassendean dunes and no wetland sites on Spearwood sands were surveyed north of Perth by Gibson *et al.* (1994). Therefore, only one species list for Dry *Banksia* Woodlands was developed for this system.

The typical and common species of community type 28 (Gibson *et al.* 1994) were included in a spreadsheet. The total number of species for this Dry *Banksia* Woodland community was 23. To achieve species richness levels similar to intact communities the species richness for Dry *Banksia* Woodland restored communities on the Spearwood system should be approximately 55 species, based on the species richness of community type 28 identified by Gibson *et al.* (1994). To increase the number of species on the Dry *Banksia* Woodland list, species occurring in more than 20 % of the plots in community type 28 were added. After these species were added, the total number of species on the Dry *Banksia* Woodland community list for the Spearwood system was 69.

3.2.3 Refining the species lists

Species lists were refined to 80 % or 50 % of the richness levels of intact communities following the process outlined below:

1. Priority food species for Carnaby's Black-Cockatoo were identified (Valentine & Stock 2008).

Carnaby's Black-Cockatoo is an endangered species, with less than 50% of the original population remaining (Garnett & Crowley 2000). The GSS study area is an important foraging area during the non-breeding season for Carnaby's Black-Cockatoo. Both *Banksia* woodlands and pine plantations have been recognised as an important food resource for this bird (Perry 1948; Saunders 1974, 1980). The removal of the pine plantations in the GSS area is expected to impact on Carnaby's Black-Cockatoo (Garnett & Crowley 2000; Cale 2003). It is therefore important that food resources for Carnaby's Black-Cockatoos are provided in restored sites.

Carnaby's Black-Cockatoo forage on a variety of food items, principally seeds from native and introduced plant species, and occasionally flowers or nectar and insect larvae (Higgins 1999). Principal native plant species include banksias, eucalypts and hakeas. On the Swan Coastal Plain, identified important native food plants include *Banksia attenuata, B. menziesii, B. grandis, B. ilicifolia, B. sessilis, B. prionotes, Corymbia callophyla* and *Eucalyptus marginata* (Saunders 1980; Shah 2006; Weerheim 2008). *Banksia* species accounted for nearly 50% of all native feeding records on the Swan Coastal Plain (Shah 2006). The majority of native feeding records are on the slender *Banksia*, *Banksia attenuata*, and this species is considered a critical food resource (Shah 2006).

The flora requirements of other native fauna currently present in the GSS area were not addressed in this report (see Recommendations).

2. Information about species form (i.e. structure), germination rates, ability to propagate by seed, performance in other restoration sites or trials (e.g. DEC, Rocla Quarry Products and Alcoa World Alumina Australia) was sourced from relevant literature.

Each species was assigned a number from 1 to 5 (code) according to the likely level of difficulty to establish the species from seeds, which was determined from the information sources included in Table 1. Species with code 1 are generally easy to propagate from seeds, although these may require pre-treatment; code 2 species are generally easy to propagate from seeds, but seed production may be small or collection difficult (and therefore seeds may be expensive); code 3 species may be difficult to propagate from seeds, but information was limited for individual species (rather than the genus) or information was contradictory; code 4 species had no information available; code 5 species are difficult to propagate from seeds due to low seed viability and germination rates, unknown or complex dormancy mechanisms, or clonal reproduction.

3. Species were removed from the lists to achieve 80 % or 50 % species richness levels, according to their structural form and difficulty of establishment using the following steps:

a) A limited number of tree species (5–7 species including the tree-like *Macrozamia* and *Xanthorrhoea* species) were identified within the *Banksia* communities. All of these were code 1 species and were retained in the 80% and 50% species lists for each community they occur in to ensure that the structure provided by trees is established at restoration sites.
b) All of the priority flora species for Carnaby's Black-Cockatoo, including all species of *Banksia*, *Eucalyptus*, *Corymbia* and *Hakea*, were code 1 species and were retained in both the 80% and 50% species lists for each community they occur in.
c) Herbs and shrubs that were assigned to code 5 were removed from the 80% and 50% species lists.
d) Herbs and shrubs that were assigned to codes 2, 3 or 4 were progressively removed from the lists according to the number of species required according to firstly their difficulty to establish from seed, then by potential seed availability.
e) No further species were removed when the reduced lists contained species that should be relatively easy to establish from seed. This will allow the DEC greater flexibility in determining the target species for restoration in any given year. The additional species removed from the list to achieve the 80% or 50% species richness levels (as indicated by the number of 'extra species' in Table 2) should first be herbs, then shrubs or *Macrozamia*/*Xanthorrhoea*, to ensure that a diverse understorey is established at restoration sites. The species removed from the list could be according to seed availability, cost or other constraints.

There are several limitations that apply to the species lists derived from the process outlined above. These limitations and associated recommendations are addressed in section 5.2.

Table 1: Information for species included in lists for restoration of post-pine sites in the GSS area, including family, form and difficulty of propagation from seed.

Code: 1 = generally easy to propagate from seed (although may require pre-treatment); 2 = generally easy to propagate from seed, but seed production may be small or collection difficult (and therefore seed may be expensive); 3 = propagation from seed may be difficult; 4 = no information available on germination; and 5 = difficult to propagate from seed. [A]Bell *et al.* (1993) except where: T = emerged from topsoil and/or BC = included in broadcast seed mix of species in studies at Rocla's restoration sites (Rokich *et al.* 2000, 2002); [B]percentage establishment in DEC trials in the GSS area (Maher *et al.* 2008).

Species	Family	Form	Seed storage[A]	Code	% estab.[B]	Comments on propagation from seed (Ralph 2003, except where indicated)
Acacia pulchella	Mimosaceae	Shrub	Soil; T; BC	1	87	Propagated from seed.
Acacia saligna	Mimosaceae	Tree	Soil	1	83	Propagated from seed.
Acacia sessilis	Mimosaceae	Shrub	Soil	1	58	Propagated from seed.
Adenanthos cygnorum	Proteaceae	Shrub	T	5		Most species are very difficult to grow from seed, and seed is difficult to collect (Ralph 2003). Established only from topsoil stored seed at Rocla restoration sites (Rokich *et al.* 2002).
Adenanthos obovatus	Proteaceae	Shrub		5		Most species are very difficult to grow from seed, and seed is difficult to collect (Ralph 2003). Established only from topsoil stored seed at Rocla restoration sites (Rokich *et al.* 2002).
Alexgeorgea nitens	Restionaceae	Herb	T	5		Plants are strongly clonal and stands typically produce little or no viable seed.
Allocasuarina humilis	Casuarinaceae	Shrub	On-plant; BC	1	60	Propagated from seed.
Amphipogon turbinatus	Poaceae	Herb	Soil	5		Difficult to grow from seed. Seed viability may often be low.
Anigozanthos humilis	Haemodoraceae	Herb	Soil	5	20	Most species are difficult to grow from seed. Despite good seed viability germination is usually very poor.
Aotus gracillima	Papilionaceae	Shrub		1		Propagated from seed.
Astartea affinis	Myrtaceae	Shrub	On-plant	1		Propagated from seed.
Astartea fascicularis	Myrtaceae	Shrub	On-plant	1		Propagated from seed.
Astroloma pallidum	Epacridaceae	Shrub	Soil	5		Very difficult to grow from seed due to complex dormancy mechanisims.
Astroloma xerophyllum	Epacridaceae	Shrub	Soil	5		Very difficult to grow from seed due to complex dormancy mechanisims.
Austrodanthonia occidentalis	Poaceae	Herb		1		Propagated from seed.
Austrostipa compressa	Poaceae	Herb		5		Many species are difficult to grow from seed.
Austrostipa flavescens	Poaceae	Herb		5		Many species are difficult to grow from seed.
Banksia attenuata	Proteaceae	Tree	On-plant; T; BC	1	87	Propagated from seed.
Banksia ilicifolia	Proteaceae	Tree	On-plant	1		Propagated from seed.
Banksia littoralis	Proteaceae	Tree	On-plant	1		Propagated from seed.
Banksia menziesii	Proteaceae	Tree	On-plant; BC	1	73	Propagated from seed.
Banksia nivea	Proteaceae	Shrub	On-plant	1		Propagated from seed.

Table 1: cont…

Baumea articulata	Cyperaceae	Herb		5		Usually propagated by division as seed germination is difficult.
Beaufortia elegans	Myrtaceae	Shrub	On-plant; T; BC	3	100	Seed germinates well but apparently many species will not grow on as seedlings e.g. B. elegans.
Bossiaea eriocarpa	Papilionaceae	Shrub	Soil; T; BC	1	67	Propagated from seed.
Burchardia congesta	Colchicaceae	Herb	Soil	1		Propagated from seed.
Caesia micrantha	Hemerocallidaceae	Herb		5		Many species are difficult to grow from seed, especially those from Western Australia.
Caladenia flava	Orchidaceae	Herb		5		The Orchidaceae family requires mycorrhizal fungus for germination and seedling development; has the smallest seeds of all flowers, and as few as one in 10,000 germinate; fewer still grow to mature plants.
Calectasia narragara	Dasypogonaceae	Herb		2		Fresh viable seed has good results, but little fertile seed is produced.
Calytrix flavescens	Myrtaceae	Shrub	Soil; T	1		Propagated from seed.
Cassytha glabella	Lauraceae	Herb		5		Difficult to grow from seed.
Cassytha racemosa	Lauraceae	Herb		5		
Centrolepis drummondiana	Centrolepidaceae	Herb		1		Propagated from seed.
Conostephium minus	Epacridaceae	Shrub		5		Propagation from seed is difficult. Seed can take over a year to germinate.
Conostephium pendulum	Epacridaceae	Shrub		5		
Conostylis aculeata	Haemodoraceae	Herb	Soil; T	1		Species from Western Australian have had poor results without treatment. Seed appears to have high viability. Smoke treatment has been successful with some species e.g. *C. aculeata* and *C. setigera*, and may be successful with other species (Ralph 2003). *C. aculeata* recorded 30.9% germination recorded for fresh seed smoked after sowing (Roche *et al.* 1997) and 27% field germination recorded for seeds aerosol smoked for 1 h before sowing (Norman *et al.* 2006). *C. setigera* recorded 60% germination with smoke treatment (Tieu *et al.* 1999).
Conostylis candicans	Haemodoraceae	Herb	Soil; T	3		
Conostylis juncea	Haemodoraceae	Herb	Soil	3		
Conostylis setigera	Haemodoraceae	Herb	Soil; T	3		
Corymbia calophylla	Myrtaceae	Tree	On-plant	1		Propagated from seed.
Crassula colorata	Crassulaceae	Herb		2		Can be grown from seed, but it is very time consuming to collect.
Cyathochaeta avenacea	Cyperaceae	Herb		1		Propagated from seed.
Dampiera linearis	Goodeniaceae	Herb	T	5		A few species are grown from seed, most others are difficult (Ralph 2003). Seedling recruitment from topsoil improved with aerosol smoke treatment at Rocla restoration sites (Rokich *et al.* 2002). Alcoa has found that the most cost-efficient propagation method for this species is cuttings (Koch 2007).
Dasypogon bromeliifolius	Dasypogonaceae	Herb	Soil; T	5		Very difficult to grow from seed.
Dasypogon obliquifolius	Dasypogonaceae	Herb	Soil	5		
Daucus glochidiatus	Apiaceae	Herb		1		Propagated from seed.

Table 1: cont…

Daviesia physodes	Papilionaceae	Shrub	Soil	1		Propagated from seed.
Daviesia triflora	Papilionaceae	Shrub	Soil	1		
Desmocladus flexuosus	Restionaceae	Herb	T	5		Plants are strongly clonal and stands typically produce little or no viable seed.
Dianella revoluta	Phormiaceae	Herb	Soil	5	0	Some species have erratic results or take 4-5 months to germinate e.g. *D. revoluta* (Ralph 2003). *D. revoluta* recorded 0% germination recorded for untreated and smoke treated seed (Norman *et al.* 2006); 35.8% germination recorded for seed smoked prior to sowing (Roche *et al.* 1997).
Dielsia stenostachya	Restionaceae	Herb		3		May be easier to grow from seed than other members of the Restionaceae family. However, usually propagated by division.
Drosera erythrorhiza	Droseraceae	Herb	Soil	5		Species from Western Australian are difficult to grow from seed e.g. *D. erythrorhiza*.
Drosera glanduligera	Droseraceae	Herb	Soil	5		
Drosera menziesii	Droseraceae	Herb	Soil	5		
Drosera paleacea	Droseraceae	Herb	Soil	5		
Epilobium billardiereanum	Onagraceae	Shrub		1		Propagated from seed.
Eremaea pauciflora	Myrtaceae	Shrub	On-plant; T; BC	1	71	Propagated from seed.
Eucalyptus marginata	Myrtaceae	Tree	On-plant	1	75	Propagated from seed.
Eucalyptus rudis	Myrtaceae	Tree	On-plant	1		
Eucalyptus todtiana	Myrtaceae	Tree	On-plant	1	87	
Gastrolobium ebracteolatum	Papilionaceae	Shrub	Soil	1		Propagated from seed.
Gastrolobium nervosum	Papilionaceae	Shrub	Soil	1		
Gompholobium tomentosum	Papilionaceae	Shrub	Soil; T; BC	1	100	Propagated from seed.
Haemodorum laxum	Haemodoraceae	Herb	Soil	1		Propagated from seed.
Hakea varia	Proteaceae	Shrub	On-plant	1		Propagated from seed.
Hardenbergia comptoniana	Papilionaceae	Shrub	Soil	1	43	Propagated from seed.
Hensmania turbinata	Hemerocallidaceae	Herb		1		Propagated from seed.
Hibbertia crassifolia	Dilleniaceae	Shrub	Soil	5		Very difficult to grow from seed (Ralph 2003). *H. hypericoides* and *H. subvaginata* established only from topsoil stored seed at Rocla restoration sites (Rokich *et al.* 2002).
Hibbertia huegelii	Dilleniaceae	Shrub	Soil; T	5		
Hibbertia hypericoides	Dilleniaceae	Shrub	Soil; T	5		
Hibbertia sp. Gnangara	Dilleniaceae	Shrub	Soil	5		
Hibbertia subvaginata	Dilleniaceae	Shrub	Soil; T	5		
Homalosciadium homalocarpum	Apiaceae	Herb		4		
Hovea trisperma	Papilionaceae	Shrub	Soil; T; BC	1		Propagated from seed.

Table 1: cont…

Hypocalymma angustifolium	Myrtaceae	Shrub	Soil	2		The seed is difficult to collect as it is shed quickly (Ralph 2003). H. angustifolium recorded 26% field germination of untreated seed and 18% field germination of seeds preimbibed in 1% smoke water for 1 h before sowing (Norman *et al.* 2006). H. robustum recorded 24% field germination of seeds preimbibed in 1% smoke water for 1 h before sowing (Norman *et al.* 2006).
Hypocalymma robustum	Myrtaceae	Shrub	Soil; BC	2		
Hypolaena exsulca	Restionaceae	Herb		5		Plants are strongly clonal and stands typically produce little or no viable seed.
Isotropis cuneifolia	Papilionaceae	Herb		1		Propagated from seed.
Jacksonia floribunda	Papilionaceae	Shrub	Soil; T	1	100	Propagated from seed.
Jacksonia furcellata	Papilionaceae	Shrub	Soil; T; BC	1	100	
Kennedia prostrata	Papilionaceae	Shrub	Soil	1	80	Propagated from seed.
Kunzea ericifolia	Myrtaceae	Shrub	On-plant; BC	1	92	Propagated from seed.
Kunzea glabrescens	Myrtaceae	Shrub	On-plant	1		
Lagenophora huegelii	Asteraceae	Herb	Soil	1		Propagated from seed.
Laxmannia squarrosa	Anthericaceae	Herb	Soil	1		Propagated from seed.
Lechenaultia floribunda	Goodeniaceae	Shrub	Soil; T; BC	3	67	Seed usually has nil to very low results without treatment (Ralph 2003). Aerosol smoke treatment improved seedling recruitment from topsoil at Rocla restoration sites (Rokich *et al.* 2002).
Lepidosperma angustatum	Cyperaceae	Herb	Soil	5		Very difficult to grow from seed.
Lepidosperma longitudinale	Cyperaceae	Herb	Soil	5		
Leucopogon conostephioides	Epacridaceae	Shrub	Soil	5		Most species have poor results from untreated seed. Viability appears to vary among species, although limited trials have been undertaken (Ralph 2003). *L. conostephioides* listed as deeply dormant and did not germinate following the first 100 days under various treatments (Tieu *et al.* 2001). *L. propinquus* recorded 0% germination for untreated and smoke treated seed (Roche *et al.* 1997) and 0% field germination for untreated and smoke treated seed (Norman *et al.* 2006).
Leucopogon polymorphus	Epacridaceae	Shrub	Soil	5		
Leucopogon propinquus	Epacridaceae	Shrub	Soil	5		
Lomandra caespitosa	Dasypogonaceae	Herb	Soil	1		Propagated from seed.
Lomandra hermaphrodita	Dasypogonaceae	Herb	Soil	1		
Lyginia barbata	Restionaceae	Herb	Soil	3		Seed propagation may be difficult, but treatments with smoke may improve results.
Lyginia imberbis	Restionaceae	Herb	Soil; T	3		
Macrozamia fraseri	Zamiaceae	Tree-like	Soil	1		Propagated from seed.
Macrozamia riedlei	Zamiaceae	Tree-like	Soil	1	40	

Table 1: cont…

Melaleuca preissiana	Myrtaceae	Tree	On-plant	1		Propagated from seed.
Melaleuca seriata	Myrtaceae	Shrub	On-plant	1	100	
Melaleuca teretifolia	Myrtaceae	Shrub	On-plant	1		
Melaleuca trichophylla	Myrtaceae	Shrub	On-plant; BC	1		
Mesomelaena pseudostygia	Cyperaceae	Herb	Soil	5		*Difficult to grow from seed. Seed production is usually low and germination is slow and erratic.*
Microlaena stipoides	Poaceae	Herb		2		*M. stipoides* is easily grow from seed, however seed collection can be tedious (Ralph 2003). *M. stipoides* recorded 100% germination and 36.7-58.8 field germination (Clarke & Davison 2004).
Millotia tenuifolia	Asteraceae	Herb		1		Propagated from seed.
Nuytsia floribunda	Loranthaceae	Tree	Soil	1		Propagated from seed.
Opercularia vaginata	Rubiaceae	Herb	Soil; T	3		Untreated seed has poor results. Smoke treatment has significantly improved germination for some species.
Patersonia occidentalis	Juncaceae	Herb	Soil; T	5	0	Seed propagation may be difficult. For *P occidentalis* best results were achieved with natural weathering for one year then smoke treatment, producing 32% germination.
Pericalymma ellipticum	Myrtaceae	Shrub	BC	1		Propagated from seed.
Persoonia saccata	Proteaceae	Shrub	Soil	5		Most species are very difficult to grow from seed.
Petrophile linearis	Proteaceae	Shrub	On-plant; BC	3		Variable results from seed. *P. linearis* and *P. macrostachya* have poor to moderate results with germination staggered over a long period. Smoke treatment may improve results (Ralph 2003). *P linearis* recorded 18.2% germination of untreated fresh seed and 36.4% germination of fresh seed smoked after sowing (Roche *et al.* 1997).
Petrophile macrostachya	Proteaceae	Shrub	On-plant	3	0	
Philotheca spicata	Rutaceae	Shrub		3		Usually very difficult to grow from seed, but some Western Australian species reportedly germinate readily.
Phlebocarya ciliata	Haemodoraceae	Herb		4		
Phyllangium paradoxum	Loganiaceae	Herb		1		Propagated from seed.
Poa drummondiana	Poaceae	Herb		1		Propagated from seed.
Podotheca angustifolia	Asteraceae	Herb	Soil	1		Propagated from seed.
Pterostylis pyramidalis	Orchidaceae	Herb		5		The Orchidaceae family requires mycorrhizal fungus for germination and seedling development; has the smallest seeds of all flowers, and as few as one in 10,000 germinate; fewer still grow to mature plants.
Pultenaea reticulata	Papilionaceae	Shrub		1		Propagated from seed.

Table 1: cont…

Pyrorchis nigricans	Orchidaceae	Herb		5		The Orchidaceae family requires mycorrhizal fungus for germination and seedling development; has the smallest seeds of all flowers, and as few as one in 10,000 germinate; fewer still grow to mature plants.
Quinetia urvillei	Asteraceae	Herb		4		
Regelia ciliata	Myrtaceae	Shrub	On-plant	1		Propagated from seed.
Regelia inops	Myrtaceae	Shrub	On-plant; T; BC	1	86	
Rhodanthe citrina	Asteraceae	Herb		1		Propagated from seed.
Scaevola canescens	Goodeniaceae	Shrub	Soil	3		Variable results occur between species from seed.
Scaevola repens	Goodeniaceae	Shrub	Soil	3		
Schoenus curvifolius	Cyperaceae	Herb		2		Grown readily from seed, but need patience to collect seed.
Schoenus efoliatus	Cyperaceae	Herb		2		
Scholtzia involucrata	Myrtaceae	Shrub	T; BC	5	0	Difficult to grow from seed (Ralph 2003). Established only from topsoil stored seed at Rocla restoration sites (Rokich *et al.* 2002).
Siloxerus humifusus	Asteraceae	Herb		1		Propagated from seed.
Sowerbaea laxiflora	Anthericaceae	Herb	Soil	5		Some or all species may be very difficult to grow from seed.
Stirlingia latifolia	Proteaceae	Shrub	Soil; T; BC	5		Most species are difficult to grow from seed e.g. *S. latifolia*.
Stylidium brunonianum	Stylidiaceae	Herb	Soil	2		Viability is usually very high but seed is not produced in great quantities (Ralph 2003). *S brunonianum* recorded 13.8% germination of untreated fresh seed and 44.6% germination of fresh seed smoked after sowing (Roche *et al.* 1997) and 39% germination of seed treated with smoke water (Tieu *et al.* 1999). *S. calcaratum* recorded 7% field germination of untreated seed and 18% field germination of seeds preimbibed in 1% smoke water for 1 h before sowing (Norman *et al.* 2006).
Stylidium calcaratum	Stylidiaceae	Herb	Soil	2		
Stylidium diuroides	Stylidiaceae	Herb	Soil	2		
Stylidium piliferum	Stylidiaceae	Herb	Soil	2		
Stylidium repens	Stylidiaceae	Herb	Soil	2		
Tetraria octandra	Cyperaceae	Herb		5		May be difficult to grow from seed.
Thysanotus patersonii	Anthericaceae	Herb	Soil	3		Variable results between species from seed. A few species have moderate to good results e.g. *T. patersonii*.
Trachymene pilosa	Apiaceae	Herb		1		Propagated from seed.
Verticordia nitens	Myrtaceae	Shrub	Soil; T; BC	3	50	Untreated seed usually has no germination; however, smoke treatment significantly increases results with many or all species.
Villarsia latifolia	Menyanthaceae	Herb		1		Propagated from seed.
Wahlenbergia preissii	Campanulaceae	Herb		1		Propagated from seed.
Waitzia suaveolens	Asteraceae	Herb	Soil	1		Propagated from seed.
Xanthorrhoea brunonis	Xanthorrhoeaceae	Tree-like	Soil	1		Propagated from seed.
Xanthorrhoea preissii	Xanthorrhoeaceae	Tree-like	Soil; T; BC	1		
Xanthosia huegelii	Apiaceae	Herb	Soil	5		Very difficult to grow from seed.

Table 2: Species lists for restoration of sites in the GSS area, with recommended options for 80% and 50% of species return.

Column: 'All' includes 15–20 more species common to the community type than would occur in intact systems; '80%' contains approximately 80% of the species that would occur in intact communities; '50%' contains approximately 50% of the species that would occur in intact communities.

Species	Bassendean									Spearwood		
	Dry			Damp			Wetland			Dry		
	All	80%	50%	All	80%	50%	All	80%	50%	All	80%	50%
Acacia pulchella	X	X	X	X	X	X	X	X	X	X	X	X
Acacia saligna							X	X	X			
Acacia sessilis	X	X	X									
Adenanthos cygnorum	X			X			X					
Adenanthos obovatus				X			X					
Alexgeorgea nitens	X			X						X		
Allocasuarina humilis	X	X	X							X	X	X
Amphipogon turbinatus	X									X		
Anigozanthos humilis	X									X		
Aotus gracillima							X	X	X			
Astartea affinis				X	X	X	X	X	X			
Astartea fascicularis							X	X	X			
Astroloma pallidum										X		
Astroloma xerophyllum	X			X								
Austrodanthonia occidentalis	X	X	X							X	X	X
Austrostipa compressa	X									X		
Austrostipa flavescens										X		
Banksia attenuata	X	X	X	X	X	X				X	X	X
Banksia ilicifolia	X	X	X	X	X	X	X	X	X			
Banksia littoralis							X	X	X			
Banksia menziesii	X	X	X	X	X	X	X	X	X	X	X	X
Banksia nivea										X	X	X
Baumea articulata							X					
Beaufortia elegans	X	X	X									
Bossiaea eriocarpa	X	X	X	X	X	X				X	X	X
Burchardia congesta	X	X	X	X	X	X				X	X	X
Caesia micrantha										X		
Caladenia flava				X						X		
Calectasia narragara	X	X										
Calytrix flavescens	X	X	X	X	X	X						
Cassytha glabella				X								
Cassytha racemosa							X					
Centrolepis drummondiana	X	X	X							X	X	X
Conostephium minus	X											
Conostephium pendulum	X			X						X		
Conostylis aculeata										X	X	
Conostylis candicans										X	X	
Conostylis juncea	X	X										
Conostylis setigera										X	X	
Corymbia calophylla				X	X	X						
Crassula colorata										X	X	
Cyathochaeta avenacea							X	X	X			
Dampiera linearis	X						X					
Dasypogon bromeliifolius	X			X			X					
Dasypogon obliquifolius	X			X								
Daucus glochidiatus										X	X	X
Daviesia physodes				X	X	X	X	X	X			

Table 2 cont.:

Daviesia triflora	X	X	X							X	X	X
Desmocladus flexuosus	X									X		
Dianella revoluta										X		
Dielsia stenostachya							X					
Drosera erythrorhiza	X			X						X		
Drosera glanduligera							X					
Drosera menziesii	X									X		
Drosera paleacea				X								
Epilobium billardiereanum							X	X	X			
Eremaea pauciflora	X	X	X									
Eucalyptus marginata										X	X	X
Eucalyptus rudis							X	X	X			
Eucalyptus todtiana	X	X	X									
Gastrolobium ebracteolatum							X	X	X			
Gastrolobium nervosum	X	X	X									
Gompholobium tomentosum	X	X	X	X	X	X				X	X	X
Haemodorum laxum										X	X	X
Hakea varia							X	X	X			
Hardenbergia comptoniana										X	X	X
Hensmania turbinata	X	X	X									
Hibbertia crassifolia	X											
Hibbertia huegelii	X									X		
Hibbertia hypericoides	X									X		
Hibbertia sp. Gnangara	X											
Hibbertia subvaginata	X			X			X					
Homalosciadium homalocarpum										X	X	
Hovea trisperma	X	X	X							X	X	X
Hypocalymma angustifolium				X	X		X	X	X			
Hypocalymma robustum	X	X								X	X	X
Hypolaena exsulca				X			X					
Isotropis cuneifolia										X	X	X
Jacksonia floribunda	X	X	X	X	X	X						
Jacksonia furcellata				X	X	X						
Kennedia prostrata										X	X	X
Kunzea ericifolia				X	X	X						
Kunzea glabrescens							X	X	X			
Lagenophora huegelii										X	X	X
Laxmannia squarrosa	X	X	X									
Lechenaultia floribunda				X	X							
Lepidosperma angustatum	X									X		
Lepidosperma longitudinale				X			X					
Leucopogon conostephioides	X			X								
Leucopogon polymorphus				X								
Leucopogon propinquus										X		
Lomandra caespitosa				X	X	X				X	X	X
Lomandra hermaphrodita	X	X	X	X	X	X				X	X	X
Lyginia barbata	X	X		X	X		X					
Lyginia imberbis	X	X		X	X							
Macrozamia fraseri				X	X	X						
Macrozamia riedlei	X	X	X							X	X	X
Melaleuca preissiana				X	X	X	X	X	X			
Melaleuca seriata	X	X	X									

Table 2 cont.:

Melaleuca teretifolia							X	X	X			
Melaleuca trichophylla	X	X	X									
Mesomelaena pseudostygia										X		
Microlaena stipoides										X	X	
Millotia tenuifolia										X	X	X
Nuytsia floribunda	X	X	X	X	X	X						
Opercularia vaginata										X	X	
Patersonia occidentalis	X			X			X			X		
Pericalymma ellipticum							X	X	X			
Persoonia saccata	X											
Petrophile linearis	X	X		X						X	X	
Petrophile macrostachya										X	X	
Philotheca spicata	X	X		X								
Phlebocarya ciliata	X	X		X			X					
Phyllangium paradoxum	X	X	X									
Poa drummondiana										X	X	X
Podotheca angustifolia							X	X	X			
Pterostylis pyramidalis										X		
Pultenaea reticulata				X	X	X	X	X	X			
Pyrorchis nigricans										X		
Quinetia urvillei										X	X	
Regelia ciliata				X	X	X	X	X	X			
Regelia inops	X	X	X	X	X	X						
Rhodanthe citrina				X	X	X	X	X	X			
Scaevola canescens										X	X	X
Scaevola repens	X	X										
Schoenus curvifolius	X	X										
Schoenus efoliatus							X	X	X			
Scholtzia involucrata	X			X								
Siloxerus humifusus							X	X	X			
Sowerbaea laxiflora										X		
Stirlingia latifolia	X			X						X		
Stylidium brunonianum	X	X		X	X		X			X	X	
Stylidium calcaratum										X	X	
Stylidium diuroides	X	X										
Stylidium piliferum	X	X		X	X							
Stylidium repens	X	X		X	X		X			X	X	
Tetraria octandra										X		
Thysanotus patersonii	X	X	X	X	X					X	X	
Trachymene pilosa	X	X	X	X	X	X	X	X	X	X	X	X
Verticordia nitens	X	X	X	X	X							
Villarsia latifolia							X	X	X			
Wahlenbergia preissii										X	X	X
Waitzia suaveolens	X	X	X							X	X	X
Xanthorrhoea brunonis				X	X	X						
Xanthorrhoea preissii	X	X	X	X	X	X	X	X	X	X	X	X
Xanthosia huegelii	X						X			X		
Total number of species	**73**	**47**	**33**	**57**	**35**	**26**	**45**	**28**	**28**	**69**	**44**	**30**
Richness of intact systems	58			37			30			55		
Extra species†	15	1	4	20	5	8	15	4	13	14	0	3

† Extra species indicates the number of additional species that could be removed when a list of species is selected to plant in any given year. The species selected for removal would be preferably herbs, shrubs, or the tree-like *Macrozamia*/*Xanthorrhoea* and would be removed according to seed availability, cost or other constraints.

4 Costs of restoration

The total cost of the restoration treatments recommended for former pine plantations in the GSS area and approximate cost of each treatment (per hectare) are outlined in Table 3. Restoration costs for the four species lists outlined in this report will be the same except for the cost of the seed, which will depend on the species included in the lists, and needs to be determined by DEC preferred seed suppliers. The costs outlined in Table 3 are based on those calculated by Reid *et al.* (2004) and apply to restoration sites using broadcast seeds. However, these costs need to be adjusted for the factors identified below, and will depend on whether DEC undertakes further investigations into site treatments and thus modifies restoration prescriptions (see recommendations in section 5.1.3 and 5.3).

- Site preparation costs including ploughing, herbicide application, and raking are likely to be lower when carried out over large areas because machinery is not limited by a small trial design.

- An appropriate method for broadcast seeding (machine or hand) needs to be identified before costs can be calculated and included in the costs of restoration.

- The cost of seed will vary according to the species mix selected (depends on the seed list, level of species richness required, and seed availability) and the quantity of seed required (see recommendations in section 5.2).

- In areas where topsoil is available for use in restoration, the amount of seed required will be much less and will therefore substantially reduce costs.

- The cost of weighing and sorting seeds is likely to be less with more efficient methods being used for broad scale restoration.

- Monitoring costs are likely to be lower because the number of species surveyed in broad scale restoration will be fewer (only targeted species will be assessed).

Table 3: Cost of various site preparation and revegetation techniques.

Activity/Resource	**Cost/ha ($)**
Burning	$964
Ploughing	$115
Herbicide	$162
Broadcast seeding	?
Raking soil over seeds	~$84 (based on cost of scarifying)
Seed	$4740
Seed weighing and sorting	$1539
Monitoring	$2760
Total cost/ha	**$10 364**

In comparison to the costs listed in Table 3, the average cost of restoration of Alcoa's post-mined jarrah forest sites is approximately $34,000 per hectare, much of which allocated to earthworks prior to ripping, reseeding, etc. (Gardner & Bell 2007). Rocla costs for restoring post-mined *Banksia* woodland sites is approximately $16,500 per hectare, which includes 2000–3000/ha for topsoil movement; 500–1000/ha for spreading the topsoil; 2000–2500/ha for additional broadcast seed; and 10, 000/ha for additional tubestock protected with tree-guards (Vern Newton, Rocla Quarry Products, pers. comm. 2009). However, these figures do not include costs of clearing vegetation, moving the overburden (top 1.5 m of soil to access the sand beneath ~$22, 000/ha), the construction of barriers around restoration sites to protect them from vandalism (found to be essential), or monitoring (considered to be minimal).

It should be noted that the vegetation communities, restoration goals, and site treatments and revegetation methods employed vary substantially among these sites and organisations. The associated restoration costs vary accordingly and will again be different to those involved in the restoration of former pine plantations in the GSS area. It is likely that the costs of restoration treatments for sites in the GSS area can only be accurately determined after undertaking restoration of initial larger scale sites (than the trials). It is also likely that, as other organisations such as Alcoa have experienced, restoration practises will need to be altered as over time as restoration practises are refined and our understanding of the system improves, and thus costs will change accordingly.

There are a range of potential threats to the success of restoration of former pine plantations in the GSS area, including: environmental weeds, the impact of extremely poor years of regeneration, and *Phytophthora*:

- The management and control of weeds will be the biggest challenge for restoration in the GSS area (CALM 1999). To minimise the costs associated with weed control it is critical that weed establishment is prevented or limited as much as practically possible. The time period between pine harvesting, site preparation treatments (e.g. burning, ploughing, etc.), and seed broadcasting thus needs to be as short as possible. Where possible, a non-residual herbicide should be applied to restoration sites after soil treatments have occurred, prior to seeding. Limiting the period of stockpiling topsoil might also reduce the accumulation of wind-dispersed weed seeds.

- The cost of extremely poor years of regeneration following the application of broadcast or mechanically sown seeds is a risk that is difficult to manage but the cost of such failures needs to be accounted for as part of the total cost of restoration. DEC should expect regeneration failure in years when rainfall is very low and also when kangaroo grazing is very high. The former might increase in frequency with ongoing changes to the climate. Effected areas may require the full suite of site preparation treatments and revegetation activities the following year. Or, if some regeneration is evident, only additional broadcast seeding may be required. However, as the cost of seeds is the most expensive component of restoration, the potential cost of extremely poor years of regeneration will be high.

- The potential impact and cost of *Phytophthora* is unknown and needs to be investigated further.

5 Recommendations

5.1 Site preparation and revegetation techniques

5.1.1 For sites using topsoil and broadcast seed

Where available, topsoil should be applied to areas to be restored following the removal of pines rather than relying on broadcast seeds alone, particularly to sites where high species diversity is required. Most of the areas that may be cleared for urban expansion near the GSS area, and subsequently the topsoil potentially available for use in restoration activities, occur on Spearwood sands. Areas that receive topsoil should be located on the same soil type and in a similar topographical location i.e. mid-slope or dune swale. Topsoil is an extremely valuable resource for restoration sites in the GSS area and it is likely that sites that receive topsoil will have greater species diversity and abundance. It is therefore essential that the locations where it is applied are strategically selected.

The following recommendations apply to sites that will be restored using topsoil with additional broadcast seeds:

1. Topsoil containing seeds should be stripped to a depth of 5 cm in autumn before the onset of winter rains. If this depth is operationally difficult, topsoil should be stripped to a maximum depth of 10 cm.

2. Topsoil should be spread on the restoration area to a depth of 2–5 cm immediately after stripping. If this depth is operationally difficult, topsoil should be spread to a maximum depth of 10 cm.

3. A seed mix consisting of species that are canopy stored, species that only release seed following fire or other major disturbances, and other species that do not recruit from replaced topsoil (see recommendations for species lists and requirements in section 5.2), should be broadcast (by machine or hand) over the restoration site following topsoil spreading. Species in the seed mix that respond favourably to smoke application should be treated with butenolide prior to broadcasting.

4. Butenolide should be sprayed over the topsoil spread on the rehabilitation area, and any additional broadcast seed, at an appropriate application rate (1–20 g of active ingredient per hectare).

5.1.2 For sites using broadcast seed only

The following recommendations apply to all restoration sites i.e. those using broadcast seeds only, or topsoil and broadcast seeds:

1. It is critical that the time period between pine harvesting, site preparation treatments (e.g. burning, ploughing, etc.), and topsoil application and/or seed broadcasting is as short as possible to minimise weed establishment. If possible, all of these activities should be carried out during the summer and autumn months.

2. Sites should be burned after pine trees are harvested to remove logging slash and pine leaf litter, and prevent prolific pine wilding establishment.

3. Sites should be ploughed just prior to broadcast seeding (by machine or hand).

4. Species in the broadcast seed mix that respond favourably to smoke application should be treated with butenolide.

5. Seeds should be broadcast in late-autumn rather than mid-winter (i.e. May rather than July).

The following treatments have had (a) no effect on restoration activities; (b) detrimental effects on restoration activities; or (c) provided similar outcomes to other less expensive treatments, and are therefore not recommended for broad scale restoration activities:
- Soil screening following stripping (for the purpose of concentrating seeds in the topsoil), for sites where topsoil will be used in restoration
- Deep-ripping of the soil
- Mulching of the restoration area
- Fencing to protect seedlings from grazing kangaroos and emus

5.1.3 Further investigations
Several site preparation and revegetation treatment options are available that have not been investigated or results have been inconclusive, which are likely to improve the success of restoration activities, and are likely to be relatively inexpensive. Further investigations to determine the effects of these following treatments would be beneficial:
- Ploughing compared with no soil cultivation on established plant diversity and density (trial sites in the GSS area are available that could be surveyed to determine this);
- Raking the soil to a depth of 5–10 mm after seeds have been broadcast, if this treatment is operationally possible over large areas;
- Non-residual herbicide on sites with low and high levels of weed cover (to be sprayed after other soil treatments that involve disturbance e.g. burning and ploughing have been carried out);
- Butenolide on broadcast seed and topsoil;
- Fertiliser on seedling growth and survival.

There are a number of other site preparation and revegetation treatments that may improve restoration outcomes, but are likely to be more expensive than the above options. Further investigations into the cost of the following treatments may be beneficial before field trials are carried out:
- Seed coating;
- Application of a biodegradable polymer gel to the soil (may be particularly beneficial on steeply sloped sites to reduce sand and seed displacement).

The extent to which soil properties may have been altered by pine plantations, and the effects that such alterations may be having on restoration trials, is unknown. Investigations comparing soil conditions such as acidity, nutrients, and fertiliser at cleared sites that supported pine plantations and in natural bushland areas will indicate whether soil conditions are likely to affect restoration success.

5.2 Species lists and requirements

The species lists developed for restoration in the GSS area could be improved by including a range of additional information that is not currently available, such as:

- Plant species lists from surveys of communities that are similar to those being restored. This is particularly important for the Spearwood community species list, which only contains information from the Gibson *et al.* (1994) surveys. The species lists presented in this report for the Bassendean system are acceptable to trial for the 2010 planting year, but would benefit from the inclusion of additional baseline data. However, the species list for the Spearwood system probably needs the addition of further baseline data before to being used in large scale restoration efforts. Ideally, species lists would be improved by including species lists from the Mattiske Consulting (2003) database, and the GSS floristic surveys (when plant identification is complete), or from additional surveys if specific communities lack information e.g. woodlands on the Spearwood system. The process for refining the species lists outlined in this report could be used once additional data has been included.
- Requirements of other fauna (mammals, birds, reptiles, etc.), for example specific flora species that provide an essential food source or habitat. These requirements are largely unknown and need to be investigated further.
- Germination cues or establishment rates of relevant species as new information becomes available, particularly for species with no information currently available or those considered difficult to establish from broadcast seeds.
- Other factors affecting species survival at GSS restoration sites, such as grazing pressure on specific species that causes no or low recruitment. For example, Norman *et al.* (2006) found that the cover of recalcitrant monocots was low in Alcoa's rehabilitated sites compared with forest due to the absence of mature Grasstrees (*Xanthorrhoea gracilis* and *X. preissii*). These species are a favourite food source for kangaroos in the post-mining restored areas and can be killed by intensive grazing pressure (Koch *et al.* 2004; Parsons *et al.* 2006). Such species should be removed from the broadcast seed mix. If the species are still required they should be planted as seedlings and protected from grazing.
- Additional species lists will need to be developed if sites are to be restored using topsoil, and include species that are canopy stored, species that only release seed following fire or other major disturbances, and other species that do not recruit from replaced topsoil. The seed storage syndrome (soil/on-plant) for species where this information is known and species that have emerged from topsoil in studies at Rocla's restoration sites are identified in Table 1. However, the species list will depend on the vegetation community from which the topsoil is sourced and may include a range of species not identified in this report. The species that do/do not emerge from replaced topsoil will need to be investigated through field and/or laboratory testing.

The ability to provide recommendations about the end point goals for the density of specific species or groups of species in mature restoration sites is limited. Plant density data has not been collected in surveys of these communities that have been carried out to date. Such information is necessary to set goals for restoration of *Banksia* woodland sites in the GSS area. There is a need to define end point goals and an appropriate trajectory of vegetation development to indicate the progress of restoration sites over time. To begin developing appropriate end point targets for plant densities, a minimum the density of individual tree species (*Banksia*, *Eucalyptus* and *Corymbia*), leguminous shrubs (e.g. *Acacia*), other understorey shrubs, and herbs (not species specific) needs to be determined. This will be most effectively determined by surveying plant densities of each community type in nearby bushland areas. When target densities for mature vegetation have been established, an appropriate trajectory can be developed for each tree species or group of species.

The ability to provide recommendations about the quantities of seed required to achieve a particular density of plants in mature restoration sites is also limited because few investigations have been conducted into germination, establishment and survival of *Banksia* woodland species. Plant establishment from seeds is dependent on a number of factors that vary from year to year (e.g., rainfall after sowing, seed viability, and seed predation) and so it may not be possible to reliably estimate the quantities of seeds needed in any given year. Some information on field establishment is available for species planted in DEC restoration trials (Maher *et al.* 2008). However, establishment rates of species included in the lists in this report should continue to be collected from DEC trial sites that were not surveyed by (Maher *et al.* 2008) or from future restoration sites in the GSS area. Survival rates of different species also needs to be monitored over time to determine the density of seedlings required at different stages of establishment, particularly in the early stages (e.g. at 9 months after planting) when corrective measures, such as infill planting, may be undertaken.

5.3 Costs of restoration

1. Phytophthora is a serious issue that has the potential to significantly affect the success of restoration activities and also the health of remnant vegetation in the GSS area. The persistence of proteaceous species will be the most affected, which are a dominant component of *Banksia* woodlands. We do not know the length of time that Phytophthora spores remain viable in soil and therefore the feasibility of restoring proteaceous species to sites that have been affected by Phytophthora.
2. The cost of several site preparation treatments and revegetation activities are likely to be lower when carried out at scale. The costs of restoration should be recalculated when the first large sites are restored and the costs of restoration can be adjusted accordingly. Lower costs in some areas may mean that seeds from a greater number of species (or species with expensive seeds) can be included or other treatments previously considered too expensive may be reconsidered if these are likely to improve restoration success.

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