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Seed Ecology: Implications for Restoration of Native Vegetation in Australian Habitats

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Introduction

Native vegetation is disappearing over large areas of Australia due to a number of causes. These include clearing for agriculture, removal of soil for mining, as well as grazing by domestic stock and introduced rabbits. To enhance efforts to restore native vegetation, data on seed stores, seed viability, and seed germination are needed. These factors are especially important in Australian ecosystems because the composition of the vegetation in the early years of restoration has an impact on ecosystem function for many subsequent years. Seed ecology issues, such as seed bank composition and seed germination, affect restoration and reclamation efforts in many different Australian habitats, and an understanding of these issues can aid in efforts to revegetate areas with native plantings.

Background and Ecology of the Region

Intense development has been occurring in Australia for only about 200 years, but in that time many fragile environments have been degraded. Since 1788, some 70% of the original plant communities have been modified, with over 65% of the tree cover removed and up to 75% of the rainforest cleared for grazing and agriculture (Saunders et al., 1990). Because of these changes, 55% of arid land and 45% of non-arid lands require some type of restorative treatment (Saunders et al., 1990).

In the southwestern area of Western Australia, particularly, the landscape has been subjected to pressures from logging, agriculture and mining. This area has a Mediterranean-type climate with a range of soil types that are typically nutrient deficient (Bell et al., 1993). Periodic fires are characteristic of the area. The vegetation is more diverse than in the eastern part of the country and is predominantly woody with shrublands, a type termed *kwongan* (Bera, 1998). Coastal woodlands containing *Banksia* species, inland woodlands containing *Eucalyptus* species (termed *jarrah* to describe the timbered areas with larger trees and termed *mallee* to describe populations of multi-stemmed shrubby eucalypts in more semi-arid regions), and both dry and wet forests are also represented (Bera, 1998). The landscape is dominated by perennials, with shrubs being the most common form, while trees are common in more moist environments. Ephemeral annuals occur in occasional habitats (Bell et al., 1993).

These Australian ecosystems are described as following the *initial floristic compositional* model. In these types of ecosystems, the composition of the vegetation in the first few years of restoration influences the ecosystem function for many subsequent years (Bell et al., 1990). Therefore, efforts to revegetate disturbed land must consider factors affecting seed germination and viability and their role in the succession of species.

Seed Ecology Basics

For Western Australian species, response to fire and type of seed storage are two factors that can be used to classify seeds when considering their germination and viability. Species that can be grouped in relation to their response to the periodic stress of fire include the ephemerals, the obligate reseeders and the resprouters (Bell et al., 1993). Ephemerals (short-lived species) tend to avoid the direct impact of fire by appearing in the first years following a fire and completing their life cycle before a second fire occurs. Much of their photosynthetic energy is directed to reproduction. A prolific amount of small seed is characteristic. The adults of the obligate reseeders are killed by intense fire and establish seedlings in the post-fire environment. These species tend to grow first vertically and then spread in their upper part, producing umbrella-shaped plants. The distinct shape fills available space between resprouting species. Reseeders tend to have shallow fibrous root systems, are typically herbaceous perennials, and can produce either large or small seeds. Resprouters make up nearly 2/3 of the species found in this region (Bell et al., 1993). These species survive fire by resprouting from protected buds under bark, from buds of underground tubers or from other underground tissue. They tend to have multiple basal sprouting branches and more of an urn shape. Trees, woody shrubs and herbaceous perennials are represented in this group. They typically set viable seed only rarely, and seedlings are uncommon.

The mode of seed storage is also an important factor to consider when classifying seeds. Many annual seeds are broadcast from the parent plant to the soil surface and are stored in the topsoil. Many other species in this area are described as serotinous or bradysporous. In these species, their annual production of seed is stored in woody protective capsules on the plant in the vegetative canopy and is only dispersed after considerable time (Bell et al., 1993). Heat may be required for the dispersal to occur.

Application to Forest Restoration

A notable feature of the soil seed bank of the jarrah forest is the near absence of seed of the dominant tree, *Eucalyptus marginata*, which has serotinous seeds (Bell et al., 1993). It is this type of forest that is typically disturbed during bauxite mining operations. The preferred revegetation practice for this disturbed land involves returning the topsoil and supplementing the soil seed store with seeds of native forest species (Bellairs & Bell, 1993). Because the emergence of the seeds tends to be variable and often low and the composition of the soil-borne seed is markedly different from the mature forest ecosystem, supplementation with broadcast seed improves the reconstruction process (McChesney et al., 1995).

Restorations of mining sites on the Darling Range of southwestern Western Australia by Alcoa of Australia show the successes and limitations of existing techniques. Since 1977, the supplemental broadcast seed mix has contained primarily jarrah forest legumes (Bell et al., 1990). In addition to supplementing the deficient nitrogen content of the post-mining environment, these native legumes quickly establish a ground cover. While seeds of most forest understory species are few in number, often inviable and difficult to collect, these legumes generally have high viability, are easily collected, and can be stimulated to germinate with a boiling treatment (Bell et al., 1993).

Adding these species to the broadcast seed has had a positive effect on restoration efforts by increasing nutrient levels in the soil and by preventing erosion, but it hasn't solved the problem of recreating the original species composition (Bell et al., 1990). Tests of the non-leguminous seed of understory species collected from the replaced soil showed that a large portion of the plants produced mostly inviable seed. Of 32 species tested, 18 had viability levels below 20% (Bell et al., 1990). The long-lived resprouting species had the lowest viability and germination percentages in the samples. This is especially problematic since these species comprise nearly 3/4 of the understory species in this jarrah forest (Bell et al., 1990). Seeds from serotinous species showed higher germination percentages but evidence indicated that they may be subject to a temperature imposed dormancy mechanism that may prevent germination in summer when hot, dry conditions may be detrimental to seedling development (Bell et al., 1990).

In order to better recreate the original forest composition, additional research into ways to stimulate seed germination is needed. Heat treatments have shown some promise and testing on additional species is recommended (Bell et al., 1993). Some other novel approaches have been tried. For example, cool smoke treatment has shown positive results in germination of broadcast seeds (Roche et al., 1997). Seed mixes used by Alcoa typically contain about 80 species; however, much of the seed shows low germination rates despite high levels of viability. To improve these germination rates, the application of aerosol smoke or smoked water was tested (Roche et al., 1997). Aerosol smoke is applied as cool smoke forced into tents placed over the site or over seed trays or naked seeds to be treated, while smoked water is produced by bubbling smoke through drums of water. Approximately 60 minute treatment periods are used for smoke applied to the soil on site, seed trays or seeds and to treat water. In plots where the forest topsoil was treated with aerosol smoke, a 48-fold increase in the total number of germinable seeds and a four-fold increase in the number of species were observed. Among the trees that responded positively was *Eucalyptus marginata*. The response in rehabilitated mine soils was also positive, but the total germinant seeds and species diversity were much lower. Improvements in germination were also found for the application of smoked water to the soil seed bank and for aerosol smoke treatment of broadcast seed. The last treatment may be the most cost effective, although increases were not as dramatic as that of soil applied smoke (Roche et al., 1997). Nursery trials at Mount Annan Botanic Gardens also confirmed that smoked water treatments produced a significant increase in the germination rates for difficult to germinate species (www.technica.com.au).

Supplementing broadcast seed with nursery grown seedlings or greenstock is another way to help recreate the original composition, especially since the mean density of seed from serotinous species is relatively low in forest soil seed stores (Bell et al., 1990). To meet this need, Alcoa of Australia helps to support plant nurseries to provide tree seedlings for reclamation of mined sites as well as for community and landcare projects in Western Australia (Alcoa Australia).

Other research has pointed to the importance of canopy and topographic effects on the germination of the dominant tree species in jarrah forest restorations. Emergence of eucalypt seedlings was found to be greater beneath a canopy than in the open areas due to a milder microclimate (McChesney et al., 1995). The benefits of an improved microclimate with enhanced soil moisture beneath a canopy was found to be of particular benefit to the large seeded eucalypt species, such as *Eucalyptus marginata* and *E. calophylla*. Emergence and establishment of seedlings was less successful at lower elevations where cold air may drain and accumulate. The percentage of emergence for *Eucalyptus marginata* was found to be three times greater at higher elevations than at low elevations, even though low sites may have had moister soil conditions. (McChesney et al, 1995) Therefore, the selection of seed by size and the area into which the seed will be broadcast are other important seed ecology factors to consider in jarrah forest restoration efforts.

Application to Shrubland Restoration

The kwongan and mallee types of native shrubland of Western Australia also present unique challenges to restoration efforts. These areas tend to exhibit very high species diversity, and restoring sites to the original species composition is often difficult, as it is in the case of the jarrah forest (Bellairs & Bell, 1993). Additionally, there are special requirements regarding the germination and distribution of the serotinous seeds that are unique to this area.

An area of kwongan near Eneabba in Western Australia is the site of mineral sand mining. A study was carried out at the Associated Minerals Consolidated Limited mining site to determine the impact of various aspects of seed ecology on restoration efforts (Bellairs & Bell, 1993). Restoration efforts there begin with the return of topsoil, if possible or, if return cannot be made directly, the topsoil is stockpiled at another location for later use at the reclamation site. If stockpiled, a mulch of plant material cut from native shrubland adjacent to the mining site is spread over the topsoil. Broadcasting of additional native seed and seed of cover-crop species follows. The study looked at the influence of the various seed sources and treatments on the restoration outcome.

Unlike efforts to simulate fire conditions through the use of smoke and heat in the jarrah forest environment, similar efforts in the kwongan environment were found to be less than successful (Bellairs & Bell, 1993). In fact, heat treatment of the topsoil was found to be detrimental. Heating soil samples to 80^{o}C did not stimulate seed germination overall and tended to kill seeds of the more sensitive species, resulting in a reduction in the size of the seed pool.

Assessment of topsoil stockpiling revealed several interesting results (Bellairs & Bell, 1993). Topsoil that had been stockpiled for only a few weeks had many more germinable seeds than did soil stockpiled for more than three years. Comparisons of seed composition between stockpiled topsoil and topsoil from native vegetation showed marked differences. Native topsoil seed stores included more perennial species, while stockpiled topsoil seed stores included a majority of annuals, many of which were non-native species. In addition, stockpiled topsoil applied to the restoration site provided fewer germinable seeds than did undisturbed topsoil, and this deficiency was not compensated for by the supplementation with broadcast seed.

The mulch that was applied to the stockpiled topsoil supplied the majority of seeds to the restoration site (Bellairs & Bell, 1993). Importantly, the mulch supplied seeds of the serotinous species that were typically not found in the topsoil. However, only a few families were represented in the mulch seed store, compared to at least 24 families found in the topsoil (Bellairs and Bell, 1993).

For areas such as these where both soil-stored and canopy-stored seeds contribute to regeneration efforts, there are special difficulties in providing propagules for restoration efforts. Harvesting of vegetation for mulch and storage of soil can disrupt the species composition by favoring annual species over perennial ones. An absence of resprouting species in the restored areas, especially serotinous resprouters, can have implications for the longer-term management of restored sites in a region where fire, drought and insect attack take their toll and resprouting is a decided advantage.

Mallee shrublands typically are more arid than kwongan shrublands and are characterized by multi-stemmed eucalypts that arise from large underground woody stem tissue swellings known as lignotubers (Onans & Parsons, 1980). Many of these shrublands have been degraded by rabbit grazing and by agricultural uses. Restoration efforts for these shrublands are beginning to occur in agricultural areas primarily used for cereal crops. In these agricultural lands, only narrow roadside remnants of mallee remain and efforts are being made to expand the native plantings. Natural regeneration of these areas typically occurs only after high intensity fires, and in areas where mature trees remain as a seed source (Bishop, 1989). Attempts to establish native species by direct seeding have met with varying degrees of success. However, direct seeding is vastly superior to natural regeneration, which may be expected to occur less frequently than once in 16 to 20 years (Bishop, 1989). Trials have shown that winter sowing is more successful than spring sowing and that weed control into the first summer after seeding is key (Bishop, 1989). Because seeds of the predominant eucalypt species in this type of shrubland are contained in the canopy, restoration efforts need to emphasize seed collection and dispersal and the role of fire in the maintenance of these areas (Onans and Parsons, 1980).

Conclusions and Implications for Restoration Efforts

Many mechanisms have evolved in Western Australia to signal seed germination at times when seedling establishment is likely to be successful. Knowledge of these mechanisms can have a positive effect on restoration efforts in a variety of habitats. Since fire is a dominant feature in this region, the maximum species diversity in these ecosystems occurs about two to five years following a fire (Bell et al., 1993). At this time, the habitat supports a mixture of individuals of resprouting long-lived species, occasional seedlings of the resprouters, more common seedlings of obligate seeding perennials and the short-lived fire ephemerals, and seedlings of the serotinous species.

Increased understanding of this complex mix of reproductive strategies is improving efforts to restore mined as well as agricultural sites. The quick return of topsoil returns soil borne seeds and appropriate mycorrhizal fungi, in contrast to long-term stockpiling which reduces seed viability and germination rates. Research on germination techniques has shown promising results from both boiling water and smoke treatments to improve establishment of native species. The provision of mulch to introduce serotinous species well as supplementation with broadcast seed and greenstock are effective methods to increase the diversity of species in restored regions. The important lesson, however, is that these fragile ecosystems with their broad diversity of plant material are not so easily restored to their original condition as initial planning may have suggested, and perhaps, further evaluation of the long-term cost and benefit needs to be done as additional pressures for mining and agricultural uses come to bear on this landscape.

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