Mine Closure 2019 - AB Fourie & M Tibbett (eds)
© 2019 Australian Centre for Geomechanics, Perth, ISBN 978-0-9876389-3-9
doi:10.36487/ACG_rep/1915_60_Horner

Bang for your buck: revegetating arid sites using coloniser species

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Abstract

Revegetation of mine sites in the arid zone is inherently challenging because of the harsh environmental conditions, low and irregular rainfall, high temperatures and winds and complex soil conditions. Issues with erosion and dust contribute to these challenges. A 'ground up' approach to revegetation was used in the recovery of a large ash storage area of arid South Australia. This approach works with the natural process of succession to build habitat; it involves sowing high densities of native colonising species. A total of 2,700 kg (15 kg per ha) of native seed was spread over 180 ha of the capped site from June 2017 to August 2017. Despite lower than average rainfall (160.3 mm in 12 months), the mean density of native plants in August 2018 was 1.8 ± 0.6 plants per m^2 (n = 50 quadrats), which represents 3.2 million individual plants across 180 ha. The standing crop of seeds for three Atriplex species (A. holocarpa, A. lindleyi and A. vesicaria) was assessed from photographs of all individuals within 10 plots, 10 × 10 m in size. Based on plant volumes and densities and scaling up for the 180 ha area, those species produced more than 500 kg of seed in August 2018; equivalent to almost a fifth of the original quantity of seed added to site. The value of this seed exceeded $76,000, and the number of individual seeds calculated for that point in time was 42.6 million. Importantly, these figures represent the standing crop for three species in August only; many colonising species produce multiple crops per annum and will increase the number of seeds (and plants) produced onsite in perpetuity. As prolific seed producers, colonising plants bolster soil seedbanks for self-sustained recovery with few other interventions or costs, providing plenty of 'bang for your buck'.

Keywords: *colonising species, dust mitigation, native seed, natural systems, revegetation*

1 Introduction

Revegetation of mine sites in the arid zone is inherently challenging because of the harsh environmental conditions, including low and irregular rainfall, high temperatures and winds and poor soil quality. Issues with erosion and dust contribute to these challenges. Finding a cost-effective and robust methodology for restoring these sites can be difficult, as traditional approaches may not allow for complex, site-specific issues that arise. The retired power station at Port Augusta provided a particularly complicated restoration site. It comprised a 272 ha ash storage area (ASA) that required revegetation to promote a stable and resilient system on the edge of a regional city in the arid zone. A 15 cm soil cap was spread across the site and a ground up revegetation approach, focusing on native coloniser species, was applied.

The ground up revegetation methodology employs the theory of ecological succession (Clements 1916) to facilitate recovery and build habitat. It involves sowing a site with seeds of native plants with a focus on high densities of diverse colonising species (generally understorey species). The application of these seeds to the site is with a cropping approach, giving a broad and consistent coverage of seed. Suitable plant species for this method and context were robust and tolerant of challenging soil chemistry and conditions, they included xerophytes (dry-plants) and halophytes (salt-plants) from the Aizoaceae, Chenopodiaceae and

Zygophyllaceae plant families (e.g. Black 1960; Jusaitis & Pillman 1997). In addition to a high tolerance for trying conditions, colonising native species are opportunistic, they thrive with disturbance, establish and reproduce rapidly in response to rain, replenish seedbanks, stabilise soil and contribute organic matter to a site. In addition to the use of colonising species this method also includes later successional stage species in the mix allowing for the development of the plant community to maturity over time.

In contrast to ground up, the top down approach in this paper primarily refers to plant species selection, but also incorporates plant density and planting methods. Typically, only a limited number of species are selected in a top down approach and these tend to be mid- and upper-storey trees and shrubs (e.g. Piggot et al. 1987; Carr et al. 2007; Nicholas et al. 2010). This can be due to the ease of collection of these species and also the desire to restore the land to the original plant community structure. Late-succession species (those dominant in mature plant communities) can take years to establish and reproduce, and the vegetation structure they create is simple (homogenous) compared to a ground up approach with a rich species selection (30 or 40 species). Line seeding or tubestock methods may be used for establishing trees and shrubs, and these approaches result in lower densities than the ground up approach used here.

Of particular benefit to arid mine site recovery is the capacity of ground up colonising species to reach reproductive maturity rapidly, some species produce seeds just weeks after germinating (personal observation). They also set large quantities of seed and can produce multiple crops per annum. The soil seedbank is often depleted on mine sites, including in areas capped with poor quality soil or rubble. The absence of a native seedbank creates a vacuum (niche) in which weed species will move into and benefit from. Colonising native species will rapidly replenish depleted soil seedbanks and provide competition to weeds. This function allows the development of a self-sustaining plant community that needs little further intervention.

The objectives of this study were to quantify the value of the ground up revegetation methodology in terms of the number of plants surviving and the standing crop of seed on the Port Augusta Power Station ASA revegetation site 12 months following direct seeding. ‘Standing crop’ in this study refers to the total number of seeds produced by three plant species at the time of the survey.

2 Methodology

The revegetation site was a 272 ha capped ASA of the Port August Power Station that closed in 2016. The soil cap was roughened lightly with a prickle chain and then the native seed was spread and turned in (with the prickle chain) simultaneously. The soil for the cap was tested and found to be consistent with the calcarosol soils of this area (Johnston et al. 2003); poor quality and characterised by high levels of salinity, alkalinity and sulphur, and low in organic carbon, nitrogen and other nutrients. Due to the scale of the site and the seeding methodology selected, no fertiliser or other additive was spread onsite. Seeding occurred from June 2017 to September 2018. For this paper, analysis was limited to the areas seeded in 2017, which covered 180 ha and was sown with 2,700 kg of native seed. The seed mix comprised 44 species, including seven grasses, 25 chenopods and 12 other locally native species. In addition to being native, many of these species were selected for their ecological traits as colonisers (e.g. ability to establish rapidly and produce abundant seed).

Revegetation growth was monitored concurrently within 50 small quadrats (1 × 1 m) and 10 plots (10 × 10 m), spread across the 180 ha site (Figure 1). Within the small quadrats, every plant was counted and identified, even tiny germinants, to produce highly accurate information on plant density. The number of plants across the site was then extrapolated from average density data collected during these intensive surveys. Within the plots, all plants that had developed past the six-leaf stage were counted, identified, measured, assessed for reproductive activity and photographed in a standardised way. A high-quality photograph (approximately 7 MB) was used to capture each plant from above. Using photographs from August 2018 (the most recent survey at the time of writing), the standing crop of seeds was determined for three species, *Atriplex holocarpa*, *A. lindleyi* and *A. vesicaria*. These species were selected because they are common and prolific seed producers onsite and because their spongy fruits are readily distinguished from the leaves in photographs (Figure 2). Seeds from other genera onsite, such as *Sclerolaena*, *Dissocarpus* and *Osteocarpum*, were not obvious in photographs and not suitable for this study.

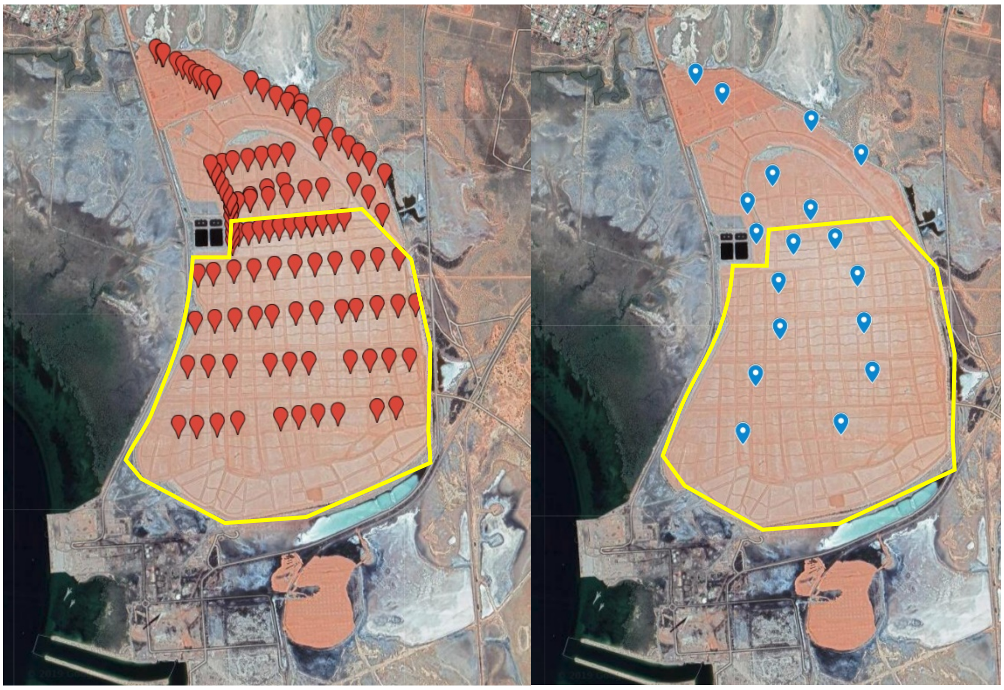
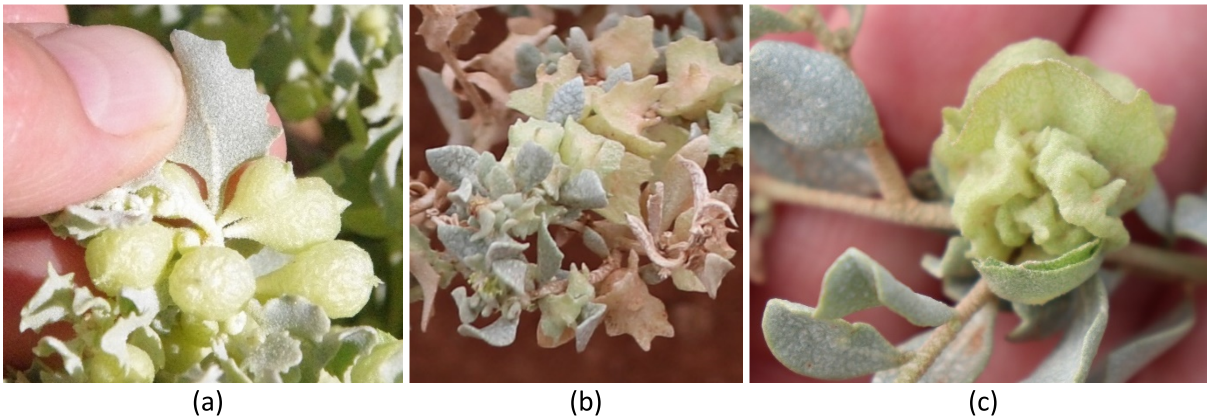


Figure 1 Location of the small quadrats (1 × 1 m; left) and monitoring plots (10 × 10 m; right) across the ash storage area of the Port Augusta Power Station that closed in 2016. The area seeded in 2017 is outlined in yellow, it covers 180 ha



(a) (b) (c)

Figure 2 The spongy fruits of (a) Atriplex holocarpa; (b) A. lindleyi; (c) A. vesicaria

To determine the number of seeds per plant from photographs, the surface area of the plant that contained 10 seeds was assessed via counting and the number of similar-sized patches was determined. As the estimate was based on a flat view of the plant, the number of seeds was multiplied by the average volume of each plant species. Volume was determined via measuring the plant's height and width (two width measures, cross-sectioned), and was collected for every plant in August 2018. The counting procedure was repeated for every *A. holocarpa*, *A. lindleyi* and *A. vesicaria* plant within 10 plots, so that the average number of seeds per plant per species was generated. Using these data, the standing crop of seeds in August 2018 was determined for the greater area (180 ha). As the number of seeds per kg for each species is known, the mass of seed produced (kg) and the value in dollar terms was quantified for that snapshot of time.

3 Results

Lower than average rainfall was recorded onsite, just 160.3 mm was recorded in 12 months from August 2017 to August 2018. The average annual rainfall at the site from 1961 to 1996 was 232 mm (Commonwealth of Australia 2019), the difference represents a 38% decline in expected rainfall. Summer temperatures were also hot, the average temperature for 2017 to 2018 summer was 33.6°C, and each month recorded 10 or more days of temperatures exceeding 35°C (Commonwealth of Australia 2019). Despite these challenging conditions, the mean density of native plants on the ASA in August 2018 was 1.8 ± 0.6 plants per m^2. Based on this density, over 3.2 million native plants have been established across 180 ha of the site.

A total of 113 plants were assessed for seed production from the three target species; of these 39 plants, or 35%, were fruiting and the abundance of their seeds calculated (Table 1). *A. lindleyi* was the most abundant species counted in the study (86%) and *A. vesicaria* recorded the greatest number of seeds per plant. Based on observed seed production in plots, the mass of standing crop of seed for the three species in August 2018 on 180 ha of the ASA would have exceeded 500 kg, which equates to more than $76,000 worth of seed. This production would equate to the number of individual seeds on the 180 ha site exceeding 42.6 million. Another 15 species were also growing onsite, and six of these were also reproducing in August 2018.

Table 1 The number of plants, number of seeds, mean ± s.e. seeds per plant, number of seeds per kilogram, and the mass and cost of seed extrapolated for the 180 ha ash storage area (ASA) of the Port Augusta Power Station for three coloniser species

Species	Total no. plants in plots (1,000 m^2)	Total no. seeds in 1,000 m^2	Mean ± s.e. seeds/plant[a]	No. seeds in kg[b]	No. kg on 180 ha of the ASA[c]	Value of seed (AUD)[d]
Atriplex holocarpa	11	1,554	141 ± 89.6	92,114	30.4	$4,556
Atriplex lindleyi	97	13,134	239 ± 59.0	130,779	181	$27,115
Atriplex vesicaria	5	8,967	1,793 ± 1,297.9	53,448	302	$45,298
Total	**113**	**23,655**			**513**	**$76,968**

s.e. – standard errors; [a] – Mean number of seeds per plant is calculated from all plants of that species in plots covering 1,000 m^2, including vegetative plants with no seeds; [b] – Swainsona Environmental Services (2017); [c] – based on densities of the plants in plots and the mean seed production for each species at the time of sampling (i.e. standing crop); [d] – Based on flat price of $150/kg.

4 Discussion

Obvious limitations exist for any study based on the extrapolation of fine-scale data to assess broader trends. Foremost in this instance is that plant density will not be uniformly distributed across large areas. Plant density did vary across the ASA, ranging from 0.1 ± 0.1 to 4.3 ± 2.2 plants per m^2 (Succession Ecology 2019). However, the identified mean on which the estimation was based (1.8 ± 0.6 plants per m^2) was calculated from a relatively high sample size (n = 50) and quadrats were spread across the site to capture the variety of conditions and success rates (see Figure 1).

Large standard errors (s.e.) were recorded for the mean number of seeds per plant, especially for *A. holocarpa* and *A. vesicaria*. It is expected that these figures were the result of the reproductive biology of these plants (only 35% reproducing), rather than from any specific issue with the methods. Typically, plants were either fruiting and loaded with seed, or were in a vegetative phase and seedless. Of the 11 *A. holocarpa* plants assessed, five had plentiful seeds and six were seedlings with zero fruits; similar observations were made for *A. lindleyi* and *A. vesicaria*.

The assessment was limited to a few species, albeit some of the most fecund ones, but of the 15 other native species counted in the small quadrat and plot surveys, six were reproducing and contributing further to the seedbank. Seed viability will vary among species, a reasonable range is 30–70% viability, which would represent 154–360 kg of viable seed produced by just three *Atriplex* species at the time of the survey. Even unsuccessful seeds (non-germinating and unviable seeds) will have a vital role in the process of site stabilisation, via the provision of organic material (carbon) to the site and as building blocks for other species (e.g. as food for invertebrates or birds attracted to the resource).

The results provide a robust estimate into the production of plants and seeds with a 'ground up' approach at an arid revegetation site in South Australia. Such an outcome would not be possible with traditional 'top down' approaches to revegetation. For example, a top down approach in species selection would have shrub and tree species still within the establishment phase onsite. It is unlikely that tubestock would have been used in this scenario because of the scale, for example (i.e. excluding labour and other externalities), the cost to establish 2.3 million tubestock plants would exceed $7.3 million (based on $2.30 per plant from Kent et al. 2002). This figure balloons to more than $26 million when a survival rate of 12% is factored in (based on unpublished data and Morgan 1999). This study provides a snapshot of selected coloniser species at a moment in time (August 2018), these plants will continue to reproduce in other months and years, such that the savings will be ongoing, and the plant community will be self-sustaining. The overall number of plants and seeds recorded was massive despite poor rainfall conditions. These results emphasise the intrinsic and ongoing value of colonising species in an arid revegetation program. Colonisers have the tools for surviving harsh conditions and their ability to germinate, grow and produce seeds in a short period, despite harsh conditions, adds value to the 'ground up' method for mine site revegetation.

5 Conclusion

The revegetation project at the Port Augusta Power station site demonstrates the capacity of colonising species to grow, survive and reach reproductive maturity rapidly despite challenging environmental conditions. The rate at which these physiological milestones are reached is key to site stability and the development of a self-sustaining system. The magnitude of the growth and the bolstering of seedbanks means few other interventions or costs are required. The approach is particularly beneficial for recovery of arid mine sites. The scale at which plant growth and reproduction occurs in 'ground up' systems provides significant financial benefits that cannot be matched with top down approaches to species selection, providing more 'bang for your buck'.

Acknowledgement

The authors thank Terry Manning and Kym Maule for their contributions to this paper.

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