Comment on restoration activities and potential outcomes at Blue Hills

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Background

Since 2009 BGPA has been engaged in developing a restoration plan and developing restoration research knowledge underpinning practical restoration for Sinosteel Midwest Corporation (SMC) at their Koolanooka and Blue Hills projects. This partnership has been the most comprehensive restoration partnership BGPA has been involved with in restoring BIF ecosystems and has been the first attempt to restore a Threatened Ecological Community (defined by Ministerial Statement 811).

The vision of the project was to develop international leading practice for the integrated restoration of post-mined BIF sites using the principle of adaptive management (management applied on the basis of lessons learnt). Applying a proven approach to ecosystem restoration of Banksia Woodlands, BGPA has explored themes with SMC such as plant community definition, soil surface reconstruction to support plant development and surface stability, soil seed bank stripping, storage and return; direct seeding technology, strategic greenstock planting and plant monitoring.

Despite no work being conducted on the rare species *Acacia woodmaniorum*, BGPA has developed a risk profile (Table 1) for the successful establishment of this species at Blue Hills off relevant information collected to date.

Table 1: Likely risk profile for stages of establishment for new populations of *Acacia woodmaniorum*

Plant stage	Risk of failure	Evidence
Viable seed production and collection	Low - Moderate	Current seed collections have been undertaken. Despite a thousand seed being collected to date it is uncertain of the extent of the collection (extensive with low seed set or restricted collection with high seed set). SMC have additional information from Curtin University highlighting seed production rates.
Germination	Low	Many *Acacia* species (including DRF taxa) have simple dormancy mechanisms that are easily overcome.
Seedling propagation for translocation	Low	Seedling growth of *Acacia* species under nursery conditions is not complex and relies on good plant husbandry practices.
Establishment of seedlings in rehabilitation substrates	Low	1. *Acacia cerastes*, a DRF species could be established outside its known distribution provided rock is a component of the substrate (Document 3 below). 2. *Acacia woodmaniorum* is growing in disturbed drill pads (pers. Observations). 3. Rehabilitation sites have greater water availability in the surface profiles compared to intact reference systems during early stages of establishment that will aid plant establishment (BGPA-SMC annual reports).
Transition to adult stage	Moderate	Once established, transition to adult stages in *A. cerastes* (Mt Gibson obs. and document 3 below) however this is unknown for *A. woodmaniorum*. Habitat studies may assist in informing target environment requirements (Document 2) and reducing current risk.
Self-sustaining populations	Moderate-High	On the basis that there is no information for any DRF BIF species. This requires longer-term research with threatening processes as well as longer-term population processes evaluated.

BIF restoration outcomes to date

Overall restoration outcomes for the Koolanooka TEC offset area (Table 2) and drill pad restoration at Blue Hills (Table 2) show that, assessed a few years after establishment, SMC have returned biodiverse systems comparable to the reference communities. This is the first demonstrated capacity to restore this level of biodiversity in BIF across the resources sector.

Koolanooka TEC - Species richness numbers were identified by using a combination of plot and transect data to generate a species area curve for a 7 Ha area (finding 84 species in total). This approach identified a species richness of 69 species (therefore a 70% target of 48 species) for a TEC reference area of 0.86 Ha, comparable to that which has been restored to date. Density data presented is for perennial species only, which account for 50.5% of the total plants identified. When annual species are included in the density counts in the restored TEC offset area are 1.86 plants/m2.

Blue Hills drill pads - To understand current industry drill pad restoration as outlined by DMP guidelines, BGPA undertook an analysis of 9 year old SMC restored pads and compared these to adjacent TEC reference plots. What was evident was that species richness and density targets were able to be obtained using current industry approaches. Investment in science resulted in increased biodiversity values of drill pads with an increase in overall species richness and an 8.5 fold increase in shrub and tree density (Table 3). Outcomes show that strategic plantings of seedlings may be all that is required to improve the biodiverse values of old drill pads, provided best practice topsoil handling has been followed.

If best practice restoration is followed then there doesn't appear to be any significant barriers to restoration over the first few years of restoration. With ongoing adaptive management programs, including threat mitigation and supplementary restoration works (plantings etc) then these biodiversity levels should be maintained.

Table 2: Number of native plants and species within the 0.86 Ha restored TEC offset area compared to species in adjacent TEC reference systems.

Site	Species richness (natives only)	Density (perennial plants/m^2)	Weed cover
TEC reference system	69 (target of 48 species for 70% return)	0.23 [1]	<1% – 5% [3]
Restored TEC offset area	102 species • 44 from TEC community • 42 unidentified native species that will include additional TEC species) • 16 from non-TEC communities	0.94 [2]	0% - <1%[3]

[1] average data recorded from 9 x 100m2 plots in the TEC reference community

[2] data recorded from the restored TEC offset area (8,581m^2)

[3] data taken from Maia 2015 environmental report for SMC summarizing whole Koolanooka rehabilitation site information rather than specifics of TEC offset area. Information compared to four surrounding reference communities.

Table 3: Number of native plants and species within 9 yr old industry standard restored drill pads (n=6, 12m x 12m plots), best practice restoration drill pads (n=3, 10m x 13m) at Blue Hills compared to species in adjacent reference systems (n=6, 12m x 12m plots).

Site	Species richness per plot	Species richness per plot (natives perennials only)	Density (shrubs + trees /m^2)
Drill pad reference system	24.2 ± 2.4	9.3 ± 1.4	0.41 ± 0.04
Standard drill pad restoration	23.2 ± 2.3	8.3 ± 1.5	0.48 ± 0.13
Restored drill pads	29.7 ± 0.9	8.0 ± 1.0	3.47 ± 1.30

In addition to these general community restoration outcomes, BGPA has previously provided advice relating to *Acacia woodmaniorum* to SMC through the following three documents.

The first document outlines the processes required to plan restoration activities to maximise restoration opportunities for *A. woodmaniorum*. This includes reference to the second document outlining the details of a habitat study required to be undertaken to identify areas for *A. woodmaniorum* restoration. The third document is a case study on another BIF DRF *Acacia* species (*Acacia cerastes*) highlighting the ability to grow the first generation of this species on a range of (but not all) substrates to maturity. These substrates indicate that the species does have growth and reproductive capacity on soils outside of its current distribution.

Although BGPA has not worked specifically on *A. woodmaniorum* it is our understanding that the following risk assessment (Table 3) may be used to guide:

Document 1: *Acacia woodmaniorum* restoration planning

This document outlines key resources and timing for maximising *A. woodmaniorum* restoration opportunities. Although the Kings Park – SMC research program did not address *A. woodmaniorum* restoration *per se*, the following can be used as a comprehensive approach to be considered prior to ground disturbance offering the leading practice approaches to restoration.

The size of the *A. woodmaniorum* restoration program is small (1600 plants to be restored): this offers a great opportunity to utilise many approaches that are not efficient when dealing with large scale restoration activities.

Step 1: Habitat study (3 months prior to ground disturbance)

In December 2016 BGPA submitted a proposal to undertake an "*Acacia woodmaniorum* habitat study" to SMC. This proposal had a detailed approach, schedule and budget to achieve the following three objectives:

1. To review previous species distribution or habitat modelling undertaken by Maia for *A. woodmaniorum*.
2. To further characterise the habitat in which *A. woodmaniorum* currently occurs; and
3. Develop a "first-pass" model for the purpose of predicting where *A. woodmaniorum* could potentially occur across the Mungada (Blue Hills) range.

The habitat study is anticipated to take 70 days and should be completed prior to translocation or restoration activities of *A. woodmaniorum*. Please consult the proposal for further information.

Step 2: Seed (October- December of each year of operation)

SMC currently have a collection of seed of the target species. Although 900 seed are currently in collections, this amount is considered small for restoration activities where survival rates of seedlings may be as low as 1-10%. A more efficient use of the current valuable seed collection is likely to occur from the generation of nursery raised seedlings. This is particularly relevant given the defined target number of individuals required to be restored (1600), allowing for more intensive propagation approaches to be explored.

If future seed collections are made direct or supplementary seeding programs may occur alongside nursery production of seedlings. Seeds will need to be treated for dormancy release prior to sowing. Although BGPA have not undertaken this research – Acacia seeds have simple dormancy mechanisms that are easily overcome and generally result in high germination percentages. Treating seeds with hot water (95° C for 1-2mins) should be a useful starting point to break dormancy. Kings Park has examined 24 species of *Acacia* as part of the research program to date with an average germination success rate of 85%.

If propagating seedlings, Kings Park usually sows 2-3 seeds per pot to ensure an emergent *Acacia* seedling. Although specific work on the species has not been conducted, a minimum success level for *Acacia* propagation is 60-70%.

For seed that is collected and requires storage before use, it is suggested that seeds be dried at low RH (15%) and then frozen. Viability of these seeds will remain unaffected if stored appropriately. This will help to ensure longevity and protection from subsequent predation.

Step 3: Plants (immediately prior to ground disturbance)

The salvage of mature plants is useful although not the primary resource for restoration activities. Plants would be salvaged prior to any impacts and plant selection should be based on genetic information for the species and distribution. Consultation with DPaW staff that generated the genetic information for *A. woodmaniorum* would be valuable.

Salvaged plants could be used in three ways: direct translocation, for seed production and for cutting production.

Direct translocation: Plants should be removed at a time when earth moving machinery is on-site. Collection of as much of the root mass as possible will assist with establishment. Plants should then be moved to large pots (to accommodate the root mass) and placed under irrigation in a nursery in natural field soils. Communication with Karara about *A. woodmaniorum* or Cliffs with other rare species would also be useful. Plants could be planted out in restoration sites the following winter when the soil substrate is moist.

Seed production: An alternate strategy could be to use the above plants collected for direct translocation and instead of planting out into restoration sites they may be used to produce seeds. This will reduce impacts on remaining extant populations and produce more regular quantities of seed for restoration. A detailed plan for establishing the seed production area should be considered to ensure genetic integrity of plant population is retained. Irrigation and fertiliser application should occur seasonally to ensure resources are maximised to assist with flowering and seed fill. Having plants in close proximity to pollinator networks will also assist in seed production.

Cuttings production: This approach is more expensive than seed propagation approaches and will usually generate limited genetically diverse materials. With 1600 plants to be impacted, there is an ability to source multiple (10-20) cuttings prior to impact from every individual ensuring conservation of genetic material. Although cuttings of *A. woodmaniorum* have not previously been undertaken by Kings Park, advice from KML via SMC highlights that cuttings success rates are very high (60-80% survival after 1 year). Cuttings should be attempted in periods of new growth and can be outsourced to nurseries in Perth with demonstrated cuttings expertise. Cuttings would need to be propagated for 6 months-1 year prior to restoration.

For all plants it would be advantageous to irrigate (at least to the median rainfall scenario) in the field at least for the first year to ensure root development for on-going resilience.

Step 4: Topsoil (at time of ground disturbance)

The topsoil seedbank is considered the most valuable source of propagules for restoration purposes and in addition to providing seed, topsoil also contains the appropriate fungal and bacterial symbionts required for promoting the successful establishment of many plant species.

Previous research indicates that maximum biodiversity return from topsoil comes from direct return, a process where topsoil is harvested from a donor site and immediately transferred to a recipient site. Stripping topsoil ideally is undertaken in the summer immediately preceding restoration activities. This requires two aspects to be simultaneously managed – the clearing of the donor (reference) and the recreation of the recipient (rehabilitation) site. Topsoil should be replaced dry during the summer/autumn period prior to restoration.

For *A. woodmaniorum*, where possible, the collection of topsoil in the immediate and more general vicinity of the plants will be invaluable prior to rehabilitation. If topsoil can't be directly returned storage may be an option however soil seed banks should be dry prior to putting into storage and then kept dry (tarpaulin) prior to use. Storage will result in the loss of some viability of the soil seedbank however this has not been quantified for *A. woodmaniorum*. It has been noted that plants of *A. woodmaniorum* are growing in disturbed drill pads where topsoil is limited, possibly indicating that topsoil is not a pre-requisite for establishment. However utilising soils associated with *A. woodmaniorum* niches will provide greater confidence that all biotic associations are preserved increasing the confidence around restoration success.

BOTANIC GARDENS & PARKS AUTHORITY

KINGS PARK AND BOTANIC GARDEN

SCIENCE DIRECTORATE

Document 2: Proposal to undertake the work "*Acacia woodmaniorum* habitat study"

December 2016

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This BGPA proposal has been developed in collaboration with the ARC funded "Centre for Mine Site Restoration" (BGPA, Curtin and SMC are partners in this ITTC) through its' Rare Species Node. The proposed study will have the following objectives and deliverables.

1 OBJECTIVES

The objectives of the study are:

- To review previous species distribution or habitat modelling undertaken by Maia for *A. woodmaniorum.*
- To further characterise the habitat in which *A. woodmaniorum* currently occurs; and
- Develop a "first-pass" model for the purpose of predicting where *A. woodmaniorum* could potentially occur across the Mungada (Blue Hills) range.

2 WORKS AND DELIVERABLES

The study will provide the following:

- Preparation of the research methodology to be used and schedule for implementation;

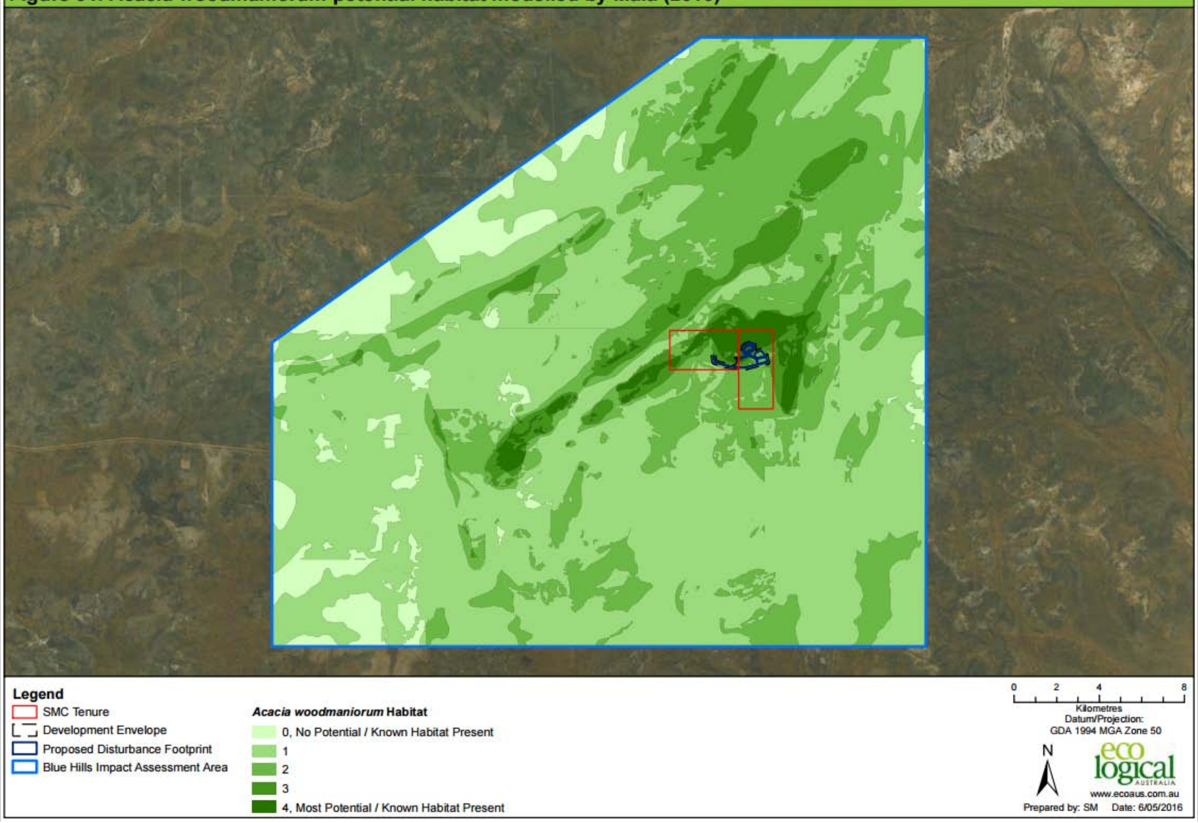
- Implementation of the study including field work and the development of a habitat model for the Mungada (Blue Hills) range; and
- Preparation of a report describing the methods used and outcomes of the study.

The research methodology and proposed schedule is to be discussed with representatives of Sinosteel Midwest Corporation (SMC) prior to implementation. The report will be presented as a draft for review by SMC prior to submission of the final version prior to the 31st March 2017.

3 APPROACH

BGPA will commence the desktop distribution modelling component upon receipt of complete environmental data sets from SMC (via CAD resources). The modelling will be based on established 'Maxent' methodology (Merow *et al.* 2013) and employ available *A. woodmaniorum* distribution data as well as environmental layers derived by CAD (elevation, geology, slope, solar radiation, 'wetness', roughness, fire and disturbance history, etc.) to the specifications required for analysis. The model of these environmental variables that best describes the distribution based on the known population area will be projected to the remainder of the Mungada (Blue Hills) range using an identical set of environmental layers covering a larger area. Initially a review of the habitat model described by Maia would be undertaken (see Figure 54 from SMC PER document below).

Figure 54: *Acacia woodmaniorum* potential habitat modelled by Maia (2016)



In a site visit during January or February 2017, BGPA will further characterise details of both occupied *A. woodmaniorum* habitat and, unoccupied sites that are highly predicted by the distribution models. This characterisation will follow the methodology of Miller (2015) and Yates *et al.* (2008 Table 2.1) in terms of site variables assessed and will be applied both for a sample of individual plants, and for a sample of sites where plants do not occur. The approach includes assessing four different types of sites, two within *A. woodmaniorum* populations and two in targeted uninhabited regions.

Table 1: Outlining the types of sites to be assessed as part of the proposed field survey.

Type	**Description**
1)	Locations of live *A. woodmaniorum* plants within *A. woodmaniorum* populations. Plants will be randomly selected and the number of habitat samples (plants) will match that of each of the following.
2)	Locations within *A. woodmaniorum* populations, sampling *A. woodmaniorum* habitat randomly – i.e., not targeted to the locations of *A. woodmaniorum* plants – by assessing environmental conditions at regular intervals on 15 transects distributed across the range of *A. woodmaniorum*
3)	Locations immediately adjacent to occupied *A. woodmaniorum* habitat, sampled by continuing the transects established in (2) above beyond the edge of the populations in the four groups.
4)	Locations in uninhabited regions that have been identified via Maxent modelling to have highest likelihood of supporting *A. woodmaniorum*. Sampling will follow the transect approach described in (2).

This approach involves ~15 transects in each of three site types replicated across the species' distribution and predicted areas. Transects will be placed perpendicular to slopes and will contain 10 sample points each. Thus, the four site types will be compared with a total of ~600 observations. We estimate this will require two teams of three people working for seven days on site.

Statistical analysis will compare the attributes of occupied and unoccupied habitat, to identify: A) if the locations of individual *A. woodmaniorum* plants differs from the general habitat in which they occur (comparing types 1 and 2); B) what features correlate with the boundaries of populations (comparing types 2 and 3), and; C) whether highly predicted but unoccupied habitat differs from occupied habitat (comparing types 2 and 4).

Soil chemical and physical samples will be collected from within populations, outside populations and highly predicted areas.

4 SCHEDULE

This schedule is subject to availability of BGPA staff, and accommodation at Mungada (Blue Hills). The table indicates the estimated number of BGPA staff days per activity.

	Jan W3	Jan W4	Feb W1	Feb W2	Feb W3	FebW4	Mar W1	Mar W2	Mar W3	Mar W4	Total days
Site methodology preparation and existing model review	Review 4										4
Modelling		Analysis 6									6
Site analysis				Field survey 48		Data entry, analysis 4					52
Report preparation								Writing		Review	

								7		1	8
Total											70

5 BUDGET

As this project requires a relatively small number of days from a large number of BGPA staff, and has a short time frame for delivery, it cannot be completed through a new appointment. Instead, it will demand the time of existing staff from other projects, requiring project backfill and compensation. Staff time, travel, consumables and analytical costs are detailed below.

Item	**units**	**@ cost**	**Total**
BGPA staff: mean rate (incl. on-costs)	70 days	$600	$42,000
Site travel	2000km	$0.70	$1,400
Data entry tablets	4	$100	$400
Soil chemical and physical analysis	60	$110	$6,600
Induction and compliance	6		In kind
Accommodation and meals	8 nights x 6 persons		In kind
Total (ex GST)			**$50,400**

6 REFERECNCES

Merow, C., Smith, MJ, and Silander, JA. (2013). A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter? *Ecography* 36: 1058–1069,

Miller BP (2015) *Tetratheca erubescens* habitat study. BGPA Final Report to Cliffs Natural Resources, March 2015

Yates C., Pettit N,, Gibson N, Dillon R, and Palmer R. (2008) The Population Ecology of *Tetratheca* (Eleaocarpaceae) on the Banded Iron Formation Ranges of the Yilgarn: An integrated research program focussed on practical outcomes for the *ex situ* and *in situ* conservation, restoration and translocation of the DRF *Tetratheca paynterae* subsp. *paynterae*. Final Report to Portman Iron Ore Limited

Document 3: Rock content of restoration substrates enhances restoration of shallow-soil endemic taxa in arid environments - A case-study of *Acacia cerastes*.

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Summary

There is a need for the restoration of plant species that are endemic to shallow, rocky and drought prone environments as a result of increased incidence of anthropogenic activities such as mining in these habitats. However, while the reconstruction of substrate profiles of rehabilitation sites is critical to the success of rare species, little is known about the specific requirements of shallow-soil endemic species and consequently the ability to re-engineer their habitat.

Research undertaken at Kings Park and the University of Western Australia (Ruoss, 2013) aimed to understand how different Banded Iron Formation DRF taxa (*Darwinia masonii*, *Lepidosperma gibsonii* and *Acacia cerastes*) could cope (survive and function) across different substrates associated with BIF landforms and surrounding areas.

The main aims of this study were to investigate environmental interactions that enable these endemic plants to occupy the hostile shallow-soil environments that will guide substrate reconstruction in restoration sites. Specifically the hypotheses tested were (1) an increase in the rock content in soil substrates improves plant survival and function by increasing the concentration of plant available water in the soil and (2) an increase in the finer particle content of soil substrates will lead to an increase in plant survival and function of shallow soil endemic species (SSES) by having the capacity to retain a greater amount of plant available water.

A field experiment was established testing the survival and function of three SSES study species (*Darwinia masonii*, *Lepidosperma gibsonii* and *Acacia cerastes*) on four soil substrates varying in rock (~1-44%) and clay (~2-6.5%) content. Plant stomatal conductance (gs) and survival were monitored for 20 months along with soil physical, chemical and

hydrological properties of sites. Only data for *A. cerastes* is presented here, to understand impacts on other taxa please see the PhD Thesis of Ruoss 2013 (UWA) – Restoration ecology of rare shallow-soil endemic flora from a semi-arid biodiversity hotspot. The full datasets are available from UWA thesis collection.

Results indicated maximum survival (>95%) occurred in rocky, gravel and sandy sites. Those plants that survived into the second summer had similar levels of plant function (gs) across these three substrates. Poor survival and plant function was observed in clay sites indicating this substrate is not suitable to facilitate *A. cerastes* establishment and survival. Although not highlighted here, the other species had significantly higher survival in soil substrates that had the highest content of rock and the highest fraction of clay and silt particles. These characteristics are believed to both increase the quantity and duration of available soil moisture with plants having access to soil moisture twice as much in the sites with high rock content. Given *A. cerastes* did not have this strict requirement, there may be greater flexibility in identifying restoration substrates suitable for plant establishment and early survival. Furthermore, with restoration sites intact after 7 years, the ability to collect longer-term survival should be explored to monitor longer-term plant survival and demographic processes (e.g. flowering, seed production). Images included in this report indicate that the initial trends observed after 20 months have continued, with many healthy plants persisting and flowering in the rocky, gravel and sandy sites.

Methods

Study site and species

The study was conducted at Mount Gibson, located in semi-arid region of Western Australia, 350 km northeast of Perth (29°36’S, 117°10’E). It is the site of a current open-pit iron-ore mining operation. The locality occurs on the boundary of the Eremaean and Southwest botanical bioregions of Western Australia (Beard 1990) which is a transition zone between the wetter southwest and dry interior of Australia. The climate of the study site is characterised by low average annual rainfall (between 250 and 300 mm) with dry hot summer months and mild wet winters with an average of 9 to 11 months of dry weather per year. Rainfall in the Mount Gibson area has averaged 289 mm per annum for the period 1905 to

2008 (Ninghan Station, Bureau of Meteorology, Australia). The January maximum temperatures average 37.3°C, July minimum temperatures average 5.4°C.

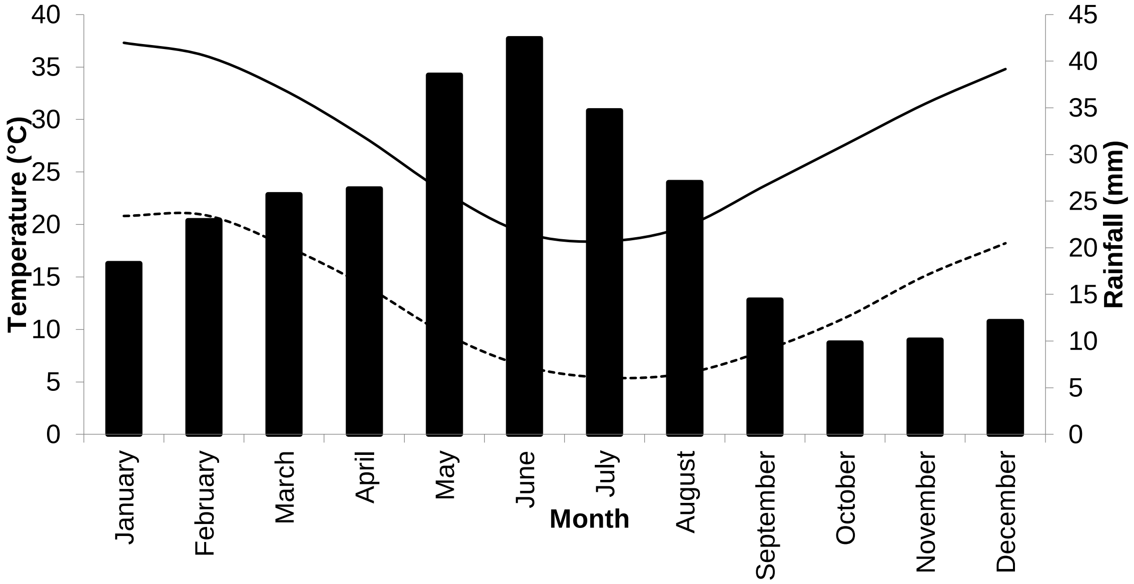

Figure 1. Average monthly rainfall per month from 1919 to 2009 (bars) and average monthly minimum (dashed line) and maximum temperatures (solid line) 1975 to 2009 (Paynes Find, Bureau of Meteorology, Australia).

The Mount Gibson range is largely composed of Banded Ironstone (BIF) (Anand and Paine 2002). High-grade hematite deposits within the BIF and are now being mined. Soils on the Mount Gibson range are general shallow (<2m) and comprised of red brown loam, on the lower slopes, increased amount of gravel is present (*pers. obs*). Adjacent to the range, the most extensive soils are granite-derived sandplains and less well drained red earths of variable depth overlying hardpans on level plains (Payne et al. 1998).

The three rare plant species in the mine footprint Mount Gibson and are listed as threatened or priority flora both at a state and federal level. *Darwinia masonii* (C.A. Gardner) (Myrtaceae) is an erect shrub to 3 m whose distribution is restricted to skeletal soils on the crests and slopes of the Mount Gibson range over a 2 × 5.5 km area with a total of approximately 16,000 plants (Department of Environment and Conservation 2008). *Lepidosperma gibsonii* (R.B. Barrett) (Cyperaceae) is a tufted perennial dryland sedge growing to a height of 0.8 m (Barrett 2007) restricted to the slopes and gullies of the Mount Gibson range and adjoining granite outcrops and breakaways (8 × 5.5 km area), a total of approximately 45,000 plants. *Acacia cerastes* (Maslin) (Fabaceae) is a tangled leafless shrub, growing to 1 m tall distributed in at least 11 populations in an approximately 20 × 15 km area centred on the Mount Gibson range associated with rock outcrops of several varieties.

Plant Establishment

A field planting trial was established in the winter (June and July), consisting of 780 individuals of each of the three study species. *A. cerastes* was grown from freshly collected seed and plants were propagated in 50 mm square forestry pots containing a native soil potting mix at Kings Park and Botanic Garden, Perth before being used in the trial. Seed was subjected to two mins of 90 °C boiling water pre-treatment to break physical dormancy. Field plants were planted in April 2009 in a grid at constant 65 cm plant and row spacing with a pottiputki planting tool.

To test the role of soil texture and rock content in plant establishment and growth, sites analogous to potential restoration substrates were selected. The 12 natural sites chosen consisted of four varying substrates and landforms: sand plain, gravel slope, rocky ridge and clay plain, with three replicates of each. Each replicate was 10 m x 10 m in size and required the clearing of all pre-existing vegetation; there were no rare plants naturally present at these chosen sites and were within the planned mining footprint. Fencing was necessary to stop plant grazing by herbivores (rabbits and kangaroos) common in the area.

Site Characterisation

The sites were characterised for a range of soil properties. Soil texture was evaluated by hand field ribbon test (Isbell 2002) and by laser diffraction method (Sperazza et al. 2004), using a Masersizer 2000 with a Hydro G wet dispersion unit (Malvern Instruments Ltd, Malvern, UK). Soils were prepared for laser particle analysis by sieving to 2 mm and a hydrogen peroxide digestion was performed to remove all organic matter. A soil moisture characteristic curve describing the relationship between soil water volumetric content and soil water potential was developed from the laser particle size analysis results following Mohammadi and Vanclooster (2011) . Bulk density was determined by the core method following Blake and Hartge (1986). A modified methodology was used for soils with a large rock/gravel content to calculate the soil volume. A small hole was dug; the gravel fraction (>2mm) sieved out and returned to the hole now lined with plastic. Water was then added to the hole, filled to ground level and the volume determined. Soil penetrability and compaction was also assessed in each of the sites by cone penetrometer to a depth of 600 mm (10 repetitions/site, CP 20 Rimik Electronics, Queensland, Australia). To understand soil chemistry as an explanatory factor for plant survival and performance, soil chemical composition was assessed for the 4 sites for pH ($CaCl_2$), Electrical Conductivity (1:5), Organic Carbon (W/B), Phosphorus Retention Index (PRI) and a range of macro and micronutrients including: N, K, B, Ca, Cd, Co, Cu, Fe, Mg, Mn, Mo, Na, Ni, P, S, Zn, As, Pb, Se (ChemCentre Western Australia, one bulked sample of 10 subsamples at 0-10 cm depth per site). Soil moisture and temperature was logged continually at 10-minute intervals with probes installed at a 50 mm depth from September 2009 to April 2011 at the 4 substrate sites (Hobo Microstation S-SMC-M003 with 3x ECH20 soil moisture probes and 1x S-TMB-M002 soil temperature probe, Onset Computer Corporation, Bourne, Massachusetts).

Plant survival and function

The planting trial was monitored for two years after planting to test the role of soil texture and rock content in plant establishment and growth. A range of demographic and ecophysiological methods were explored in this study. Demographic monitoring was undertaken at eight time points (September and November 2009, February, April, July and October 2010 and March and April 2011) when height, diameter and live status were assessed for all plants. Ecophysiological measurements were undertaken at three time points: at the end of the first and second summers (February 2010 March 2011) and first winter (October 2010). Plant survival was assessed at the end of the experimental period.

To understand plant function as related to soil water availability, leaf stomatal conductance to water vapour (g_s) was measured on plants *in situ* using a Li-Cor portable infrared gas analyser (Li-6400, Li-Cor Inc, Lincoln, Nebraska). Measurements were recorded between the hours of 1000 and 1200. For sampling *L. gibsonii* and *A. cerastes* an artificial light source was administered via a Li-Cor red/blue LED chamber (6400-02B) with a saturating irradiance of 1700 μmol$m^{-2}s^{-1}$, which on average is equivalent to ambient full sunlight conditions. Leaf chamber CO_2 concentration was maintained at 400 μmol mol^{-1} using a CO_2 mixer (6400-01) with a flow rate set at 300 μmols^{-1}, chamber temperature was maintained at ambient. Measurements were made on the youngest, fully formed, healthy leaves on each plant. Five replicate readings were made on each plant sampled when chamber conditions were stable. A total of five plants at random were sampled of each species at the twelve sites, totalling 180 plants.

Statistical Analysis

All data was analysed by ANOVA to determine significant differences between treatments within species. Tukey's post hoc testing was used to determine where specific treatment differences occurred. Data not adhering to the assumptions of ANOVA were transformed accordingly; untransformed data is presented in all figures and tables. All significance is at $\alpha = 0.05$, reported values are means with ± standard error, unless otherwise stated. Statistical testing was undertaken with SPSS Version 17 (IBM Corporation, New York).

Results

Plant Survival

There was a significant effect of soil substrate on total plant survival in each of the three study species. *Acacia cerastes* had very high survival in three of the four study sites with the Rocky Ridge (99.5%), Gravel Slope (95%) and Sand Plain (94%) all having a significantly greater survival than the Clay Plain site (14%) (Figure 2). Imagery highlights healthy plants persisting in large numbers in three of the four substrates, with only clay plain have minimal survival (Figure 3).

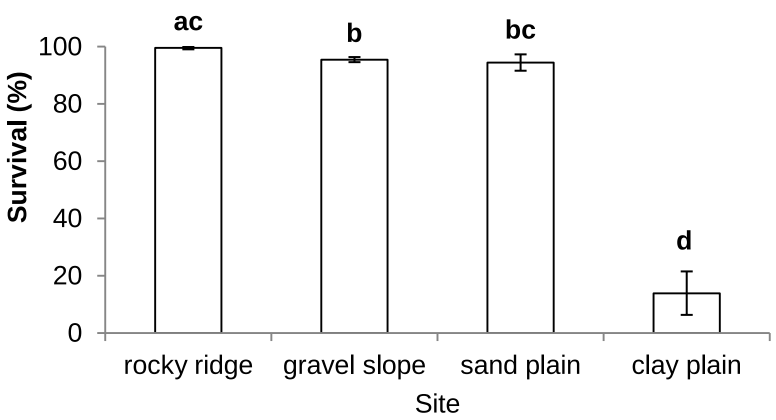

Figure 2. Survival of study species planted in four differing substrates (a) at the end of the 20 month establishment trial. Values shown are means ± SE (n=195). Differing letters within species indicate significant differences between sites.

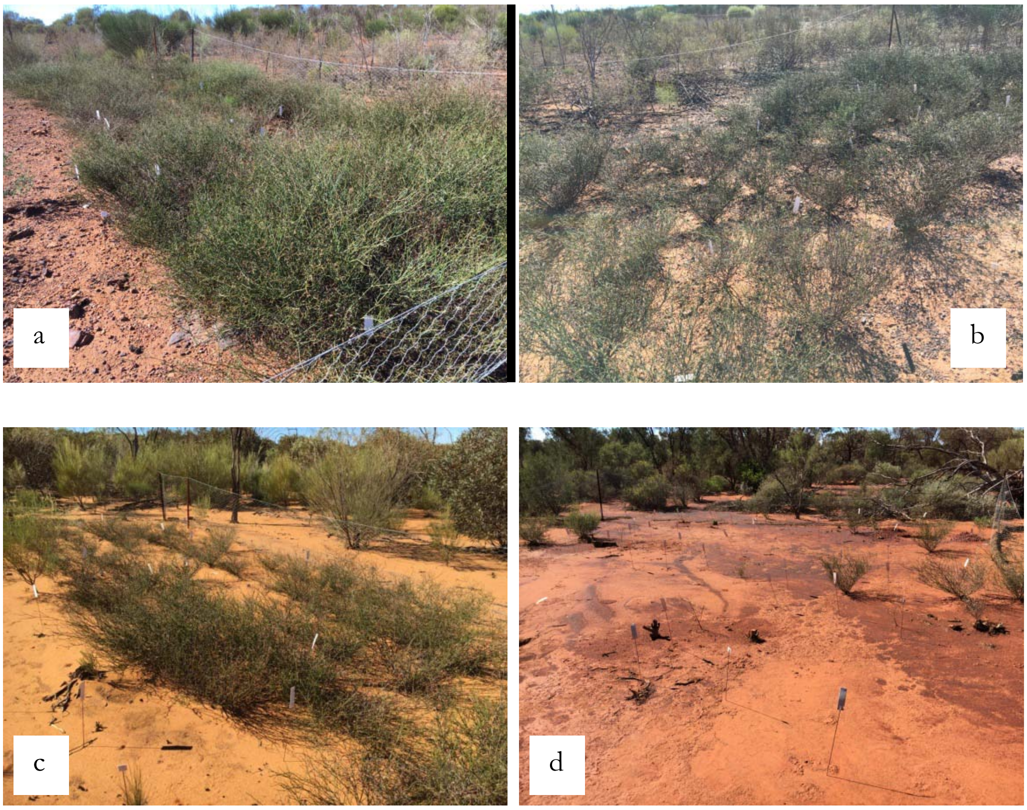

Figure 3. Plant survival of *A. cerastes* after ~7.5 years on the four substrates (a) rocky ridge, (b) gravel slope, (c) sand, (d) clay.

Plant function

Stomatal conductance for *Acacia cerastes* in the first summer, showed significantly higher levels in the Rocky Ridge (0.23 mol H_2O m^{-2}s^{-1}) and Gravel Slope (0.20 molH_2O m^{-2}s^{-1}) sites compared to the remaining sites (Figure 4). In the first winter the Rocky Ridge site still had the highest stomatal conductance (0.21 mol H_2O m^{-2}s^{-1}) whilst the Clay Plain site had the lowest (0.6 mol H_2O m^{-2}s^{-1}). In the second summer, stomatal conductance at all sites dropped considerably, values ranged from 0.04 mol H_2O m^{-2}s^{-1} in the Sand Plain site to 0.003 mol H_2O m^{-2}s^{-1} at the Clay Plain site.

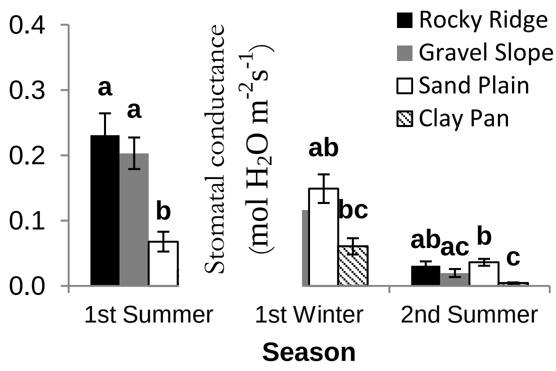

Figure 4. Mean stomatal conductance of *A. cerastes* on four substrates measured seasonally over a 20 month period. All values are means ± SE (n=15). Differing letters indicate significant differences over sites within seasons.

Soil Physical Properties

Gravel Content

Rock and gravel content differed significantly between the four study sites (Figure 5A) with the Rocky Ridge and Gravel Slope sites having similar, high gravel contents (44% and 42% of mass, respectively) and the Sand Plain and Clay Plain sites having very low gravel content (0.73% and 3.20%).

Soil Texture

The soil texture analysis of the four study sites showed clear differences in sand, silt and clay content (Figure 5B). Clay content was greatest in the Rocky Ridge site (6.5%) more than double that of the Gravel Slope site and than three times that of the Sand Plain and Clay Plain sites. Silt content was also highest in the Rocky Ridge site (23%) with the Gravel Slope and Clay Plain site having approximately half that amount present, while the Sand Plain site had only 2% silt. Sand content highest in the Sand Plain site (98%), and lowest in the Rocky Ridge site (70.5%). The Gravel Slope and Clay Plain sites were 85% and 89% sand. These soil texture results define the Rocky Ridge as a sandy loam, Gravel Slope as a loamy sand, Sand Plain as a sand and Clay Plain as a sand clay loam (United States Department of Agriculture 2012).

Bulk Density

The bulk density of restoration substrate sites ranged from 1.20 g/cm^3 to 1.62 g/cm^3 (Figure 5C). The lowest bulk density was measured in the Rocky Ridge site, which was significantly lower than the Sand Plain (1.57 g/cm^3) and Clay Plain sites (1.62 g/cm^3). The Gravel Slope had a bulk density of 1.41 g/cm^3, which was not significanly different to the other sites.

Penetrability

Maximum penetrable depth varied widely between restoration sites, with a mean range between 143 and 589 mm in depth (Figure 5D). Note that maximum depth possible with this method was only 600 mm and depths below that would have been possible at the Sand Plain site had equipment allowed. Nevertheless, the Rocky Ridge and Gravel Slope were not significantly different with a mean of 143 mm and 182 mm respectively. These sites were however significantly less than the Sand Plain and Clay Plain sites. The Sand Plain site was also significantly higher (589 mm) than the Clay Plain site (390 mm).

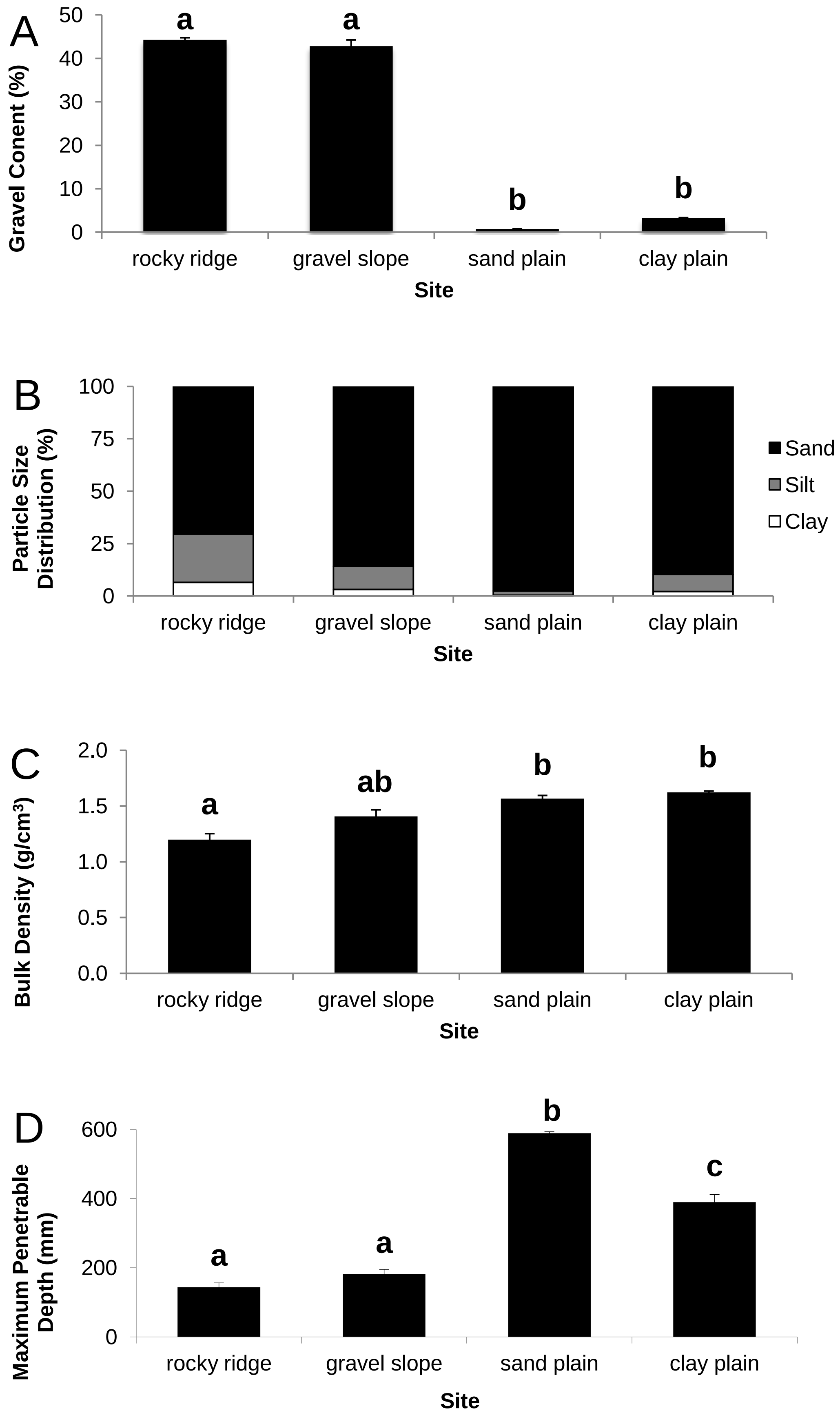
A
Gravel Conent (%)
50
40
30
20
10
0
a
a
b
b
rocky ridge
gravel slope
sand plain
clay plain
Site
B
Particle Size Distribution (%)
100
75
50
25
0
Sand
Silt
Clay
rocky ridge
gravel slope
sand plain
clay plain
Site
C
Bulk Density (g/cm³)
2.0
1.5
1.0
0.5
0.0
a
ab
b
b
rocky ridge
gravel slope
sand plain
clay plain
Site
D
Maximum Penetrable Depth (mm)
600
400
200
0
a
a
b
c
rocky ridge
gravel slope
sand plain
clay plain
Site

Figure 5. Soil properties of of the four study sites at Mount Gibson investigated including (A) Mean substrate gravel content (>2 mm) Mount Gibson(n=3), (B) soil texture derived from particle size analysis using the laser diffraction method, (C) bulk density (n=3) and (D) maximum penetrable depth (n=30). All values are means ± standard error. Differing letters indicate significant differences.

Soil Moisture

Soil moisture at 5 cm varied across restoration substrate trial sites, with higher soil moisture occurring in the Rocky Ridge and Gravel Slope sites for relatively longer periods (data not shown). Measured soil moisture exceeded volumetric field capacity for a total of only 2 days at the Rocky Ridge site and no other sites reached this mark. The period of time during which soil moisture content remained between field capacity and wilting point (i.e. period when soils held water that was available to plants) was longer in the Rocky Ridge and Gravel Slope sites and were observed during 12% and 13% of the survey period respectively. This was twice as long as was observed in the Sand Plain and Clay Plain sites –6% of the observation period in both sites. While soil moisture measurements at 5cm depth may not be representative of water available at greater depths, we expect that these results are indicative of patterns in these soils at greater depth as well. It is also to be noted that autumn and winter of 2010 were particularly dry, with observed rainfall (122.4 mm) significantly below the average for that period of 207.9 mm.

Brief discussion

The current results indicate that *A. cerastes* has the ability to establish, survive and reproduce on a range, but not all of, the substrates tested. For example, clay plain soils do not appear to support reliable establishment (<15% survival after 2 years and likely to be close to 0% after 7 years). Confidence can be gleaned from the fact that plants are persisting in a healthy state and in large numbers after 7 years in the three remaining sites tested. This is particularly promising given the rainfall during establishment and over this time has been below the long-term average.

It is important to note that these sites were fenced and cleared prior to the trial commencing, therefore herbivore impacts and competition with co-occurring species was alleviated to some degree. Understanding the life history traits of any DRF species (e.g. how these species recruit and compete for resources) in more natural systems may provide further clues to their ability to persist in different parts of the landscape.

A search of Florabase collection records indicates that this species is present off the Mt Gibson range, in sandy substrates, and its presence may be linked to disturbance events (e.g. road-side grading). Understanding how disturbance events correlate with species presence will be important not only for this species but for other Acacia species, where disturbance (e.g. fire or physical soil disturbance) increases recruitment opportunities. Although recruitment of BIF endemic Acacia seedlings isn't dependant on disturbance (e.g. *A. woodmaniorum*, Maslin and Buscumb 2007), an understanding that the current presence of the species may not necessarily provide the full potential distribution of this species or other taxa is important when considering overall impacts on a species, however this requires significantly more research to be undertaken.

Other SSEPS species are more restricted so it is not possible to translate the *A. cerastes* finding to other BIF endemic species, without the scientific research. Species within the Acacia genus are however likely to have similar triggers to establishment. Seed dormancy is easily overcome in many Acacia species however substrate and environmental interactions may be more species specific.