FEATURE

doi: 10.1111/j.1442-8903.2010.00508.x

Ecological restoration of cleared agricultural land in Gondwana Link: lifting the bar at 'Peniup'

By Justin Jonson

Early results of a 250-ha direct seeding and planting project show that innovative planning and implementation techniques can go a long way toward bridging the gap between theory and practice

Justin Jonson worked for 3 years as Greening Australia's Restoration Manager in Gondwana Link. He now works as a Restoration Consultant and Contractor based with Gondwana Link (PO Box 5276, Albany WA 6332 Australia; Tel: 0427 190 465; Email: justin@gondwanalink.org). This article documents a range of restoration approaches applied and/or developed by the author, with the support of the Gondwana Link/Greening Australia team, that may be useful for other restoration projects.

Introduction

Gondwana link is an ambitious conservation and restoration initiative located in the southwest of Western Australia (WA). This regional scale effort involves a number of organisations, communities and individuals, working collaboratively to reconnect and conserve landscapes from the tall wet forests of the far southwest to the dry woodland systems bordering the Nullarbor Plain (Fig. 1). Through the restoration of cleared lands, and the management and protection of existing remnants, the effort aims to restore ecosystem function and secure native habitat within a biodiversity hotspot (Bradby 2008).

One area in which operational activities have focused within Gondwana Link is a 70 km section of fragmented mallee and woodland remnant vegetation systems located between the Stirling Ranges and Fitzgerald River National Parks, referred to as the 'Fitz-Stirlings'. The old, weathered and nutrient poor soils of the region have been spared from recent glaciations, and now support an extremely diverse and ancient flora (Hopper & Gioia 2004). Endemism in the southwest Australia is high (49%), with flora distributed in a patch-like mosaic of diverse plant communities which, in turn, provide a large range of habitat types. The climate of the area is

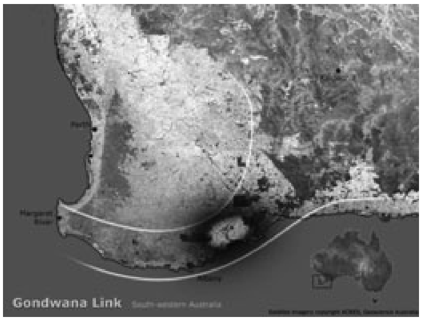

Figure 1. Gondwana Link is an ambitious vision of conservation and reconnection, stretching 1000 km from the karri forests of Australia's southwest corner to the woodlands and mallee bordering the Nullarbor Plain. The Fitz-Stirling area in which this project is located, is highlighted.

Mediterranean, with average annual rainfall of 456 mm (1963–2008), of which 72% falls in the cooler months from April to October (Bureau of Meteorology, Jerramungup).

The Fitz-Stirling region provides an excellent opportunity for the practice of ecological restoration at the landscape scale. While land clearing for agriculture has occurred, significant areas (27%) of remnant vegetation are still present (Deegan & Sanders 2008). These remnant islands of biological diversity can provide sufficient seed sources for restoration activities.

In the southwest of WA, the natural transition of cleared agricultural land back to native vegetation systems is obstructed by both biotic and abiotic thresholds (Cramer *et al.* 2008). Foremost among them is the biotic challenge of a dispersal limited flora. This barrier to re-establishment is further compounded by an abiotic legacy of chemical residues created through decades of fertiliser use. Such changes to soil nutrient levels facilitate the persistence of exotic weeds. Active restoration is therefore required to facilitate recovery (Whisenant 1999; Suding *et al.* 2004). Direct seeding of native plant species into cleared lands has been demonstrated to be an effective method for this process.

The Peniup Restoration Project

In July 2007, Gondwana Link groups Greening Australia and Bush Heritage Australia co-purchased the 2406 ha 'Peniup' property. The purchase aimed to facilitate the protection of existing bushland on the property and restore key habitats and ecological linkages in the Fitz-Stirling operational area (Fig. 2).

Restoration objectives

The Peniup Restoration Project aims to re-establish a self-replicating biologically diverse plant system, ecologically informed in its design, and consistent with the heterogeneous mosaic of plant associations found in the Fitz-Stirling landscape. Because of the scale and complexity sought for the proposed restoration, new approaches to restoration planning, new direct seeding equipment and new implementation techniques were required to bridge the gap between theory and practice.

Informed by the alternative stable states model of community assembly (Temperton & Hobbs 2004), detailed approaches were required to restore the richly diverse mosaic of different vegetation associations. For a dispersal limited flora, as demonstrated in the southwest of WA, initial species composition sets the trajectory of long-term development for a plant community. The challenge was to move away from seed mixes that reflected 'mixed soup' conglomerations of species collected from various locations, to defined plant assemblages that reflected specific soil types and landscape positions. Millions of years of evolution have selected the most resilient systems for local climatic and edaphic conditions, and that evolutionary evidence should be used to inform practice.

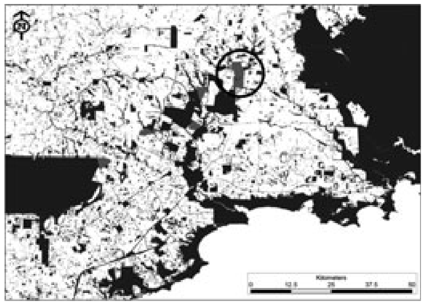

Figure 2. A key strategy for the achievement of the goals of Gondwana Link is purchase of key lands for conservation and restoration. Properties purchased by groups involved in Gondwana Link within the Fitz-Stirling Landscape are pictured here (Peniup is circled).

While re-establishing native plant systems was the primary objective, there was also an additional objective of overcoming other ecological thresholds (Whisenant 1999), such as those required for development of suitable habitat for local fauna [as listed and described in the Fitz-Stirling Functional Landscape Plan (Deegan & Sanders 2008)]. The challenge here was to move away from linear rows of woody vegetation, to more spatially diverse and random plant patterns which included both dense thickets and open spaces.

Throughout the project, an ongoing referral to ecological theory (Hobbs & Harris 2001; Fazey & McQuie 2005) ensured restoration approaches were consistent with the project goals and ecological processes underpinning them. This required an appropriate balance of field work, desktop analysis and hands-on project management.

Restoration approach

To achieve these objectives, a four stage approach was applied. The first stage entailed the development of a map, which defined the soil/landscape units across a 950-ha northern section of the property. The second stage was the development of nine vegetation associations, which defined plant groups for each soil/landform unit. The third stage was the development of a new direct seeding machine able to sow seeds in a way which assisted the development of more structurally and spatially diverse plant communities. These three planning components were then applied to a fourth stage through the establishment of a 250 ha biodiverse carbon-funded restoration project.

Stage 1. The planning process

For this component, a spatially explicit planning and mapping approach (GIS) was used to manage a wide range of biophysical information. This began with the collection of site information from the departing farmer. Thirty years of farming on site provided insights into broad soil types, crop yields, clearing history and site-specific hydrology.

Following this, two different soil surveys were undertaken. The first was a depth analysis for 16 excavated pits positioned to broadly survey the major landform units. An excavator was used to dig to a depth of 3 m or until an impermeable layer was reached. This survey was followed up with a second highly detailed survey of 100 hand augured soil cores sampled to a depth of 1 m. Sample locations were spatially distributed across the site informed by changes in topography and soil surface characteristics. Detailed information for each core was collected including soil texture, colour and profile depth records. Photos were taken of each change in soil profile horizon, and GPS (global positioning system) coordinates recorded for every pit and core.

GPS coordinates and accompanying data were converted into GIS shapefiles with data attribute tables. Additional geospatial datasets were then used to assist in defining subsurface soil formation boundaries. Datasets used for this process included Department of Agriculture WA subsystem soil mapping, a locally developed vegetation map (Newbey 1979), a 10-m digital elevation map (DEM) and a gama-radiometrics map (Fig. 3). These layers were overlaid and compared, along with the soil sample descriptions and photos, to systematically bulk similar soil types into broad groups.

Restoration map

Once subsurface soil boundaries were broadly defined across the site, a 'restoration map' was produced as a GIS shapefile to delineate boundaries between each type (Fig. 4). As the map was developed to serve as a template for the re-establishment of native plant systems, consideration of topography, contour layout and operational feasibility were included in its design.

Stage 2. Developing vegetation associations: from mixed soup to defined plant communities

Following the development of a soil/landscape 'restoration map', the next step was the allocation of plant species to their appropriate soil types. The highly heterogeneous distribution of plant communities across the Fitz-Stirling is not easily replicable. There is both high endemism confined to discrete areas throughout the mosaic, and ubiquitous species found in many locations across the greater landscape. In addition, our capacity to re-create plant communities was restricted to the species from which seed was able to be collected.

A plant species list compiled on site for this project recorded 243 native species within the existing remnant vegetation. This count is likely to under represent the actual diversity of the site as it focused on the main structural elements, and had low identification of herbaceous and ground cover species due to time and resource constraints.

Genetic studies within the south-west floristic region have found that even wide spread species often demonstrate significant genetic differences (Krauss & He 2006). In light of this and the precautionary principle, our efforts focused on sourcing seed from plant species with local genetics. Professional seed collectors were able to collect an impressive 120 species from across the site. Experience in previous Gondwana Link projects had shown that the on-ground knowledge of seed collectors can be a valuable asset in restoration efforts. An example of this was the spatial information of where each seed batch was collected for this project reported by seed collectors. Such information can later be used to track the genetics of newly propagated plants.

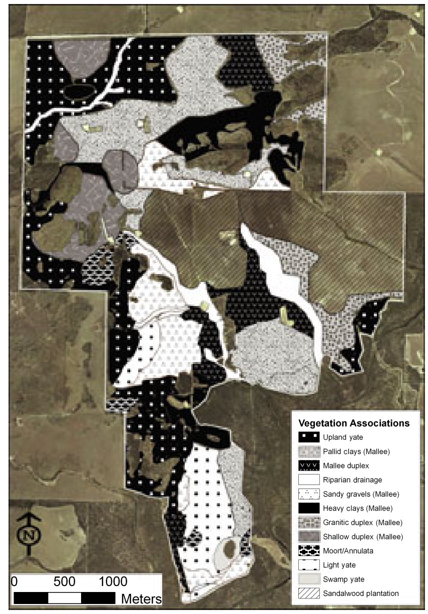

Figure 4. The Peniup 'Restoration Map' identifies the boundaries between soil/landscape units providing a template for the re-establishment of associated plant species in a patch-like mosaic.

Using the soil/landscape units defined in the 'restoration map', each of the collected plant species was assigned to its appropriate association, or associations based on its known affinity for a soil landscape zone. A number of data sources were used to inform this coupling of species and preferred soil landscape type, including consultation with local seed collection and flora experts, site-specific

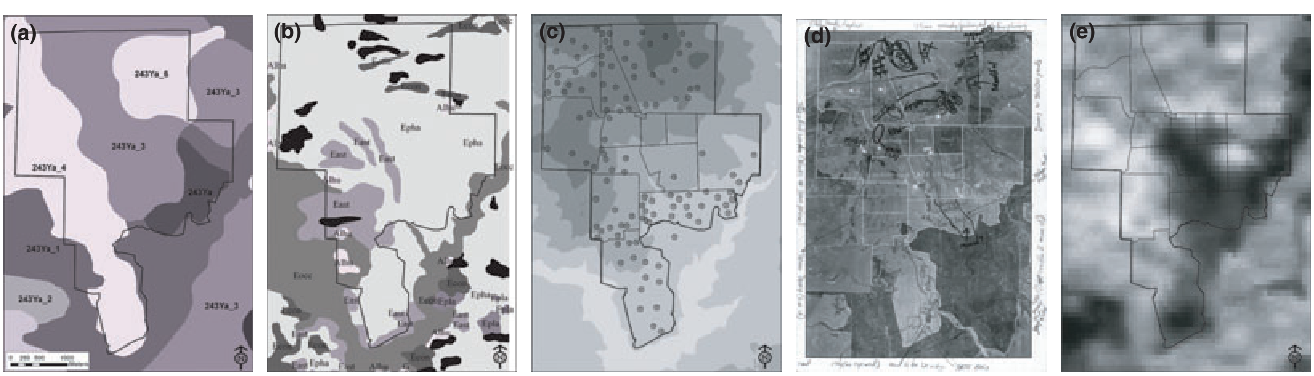

Figure 3. Soil survey and mapping was undertaken to identify soil/landform units to which floristic assemblages could then be mapped. The geospatial datasets pictured here are (a) AgWA subsystem soil map, (b) Newbey Vegetation Map, (c) DEM with soil sample locations, (d) notes collected from farmer and (e) gama radiometric layers, were used for further defining patch scale soil boundaries.

notes on remnant vegetation and soil type, information from previous studies (Newbey 1979) and empirical observations gained from the Fitz-Stirling vegetation mosaic. The result of this analysis was the development of nine vegetation associations linked to corresponding soil landscape types. Further details on these associations and soil landscape units are available at http://www.gondwanalink.org/Peniup_VegAssoc.pdf.

As on-ground works in 2008 were partly funded through a carbon contract, an ecotone vegetation association was also developed to make best use of a productive loamy-gravel soil type. This was carried out in a way which merged project objectives with biomass production goals. The tall woodland tree known as Yate (*Eucalyptus occidentalis*) is consistently found in riparian zones, swampy areas and on granitic loam soil types. It demonstrates the highest carbon-carrying capacity of trees in the local landscape. Revegetation projects from other regions have shown that Yate can survive and grow well in a large suite of different biophysical conditions. However, it is unclear whether Yate can persist into the long-term on 'light soils' located in non-water gaining sites, particularly in the face of climate change. To gain valuable carbon yields, while also accommodating for the risk of medium term mortality, a plant system combining species from both the 'Upland Yate' and 'Gravel' vegetation associations was developed. The resulting system, termed 'Light Yate', has the capacity for both high biomass production (from the Yate), as well as an inbuilt capacity for long-term viability (from the lignotuberous mallee species). It is anticipated that this system may provide an increased level of ecosystem services such as higher carbon sequestration and more rapid development of faunal habitat, while also representing a resilient plant community able to respond to future disturbances such as fire and drought. A total of 46 ha of this vegetation association was implemented in 2008. Yate seedlings were hand planted to a density of 350 stems/ha, while the rest of the species for this vegetation association were direct seeded.

Using direct seeding to re-establish native plant communities

When re-establishing native plants through direct seeding, a number of management decisions can play a large role in the resulting community composition and structure. Building seed mixes requires consideration of application rates for each of the species used and variables of their individual dominance, structural form and lifecycles. Planning which aims to achieve appropriate populations of individual species, based on their mature size and form, can help with the emergence of structural complexity. For Peniup, estimates of potential canopy areas at maturity for each plant-group size category were considered when determining preferred stocking rates. The goal was to establish an assemblage of species that provided a diverse structure and sufficient canopy cover (~85% at maturity).

Leading into the project, no quantified information from local or published sources was available to guide seeding input rates and expected seedling establishment numbers. In addition, variability in total seed-mix rates used by local practitioners had ranged from 450 to 800 g/ha. This variability was further compounded by differences in species used, seed sizes, seed viability and seasonal differences from project to project.

One such example is within the genus *Eucalyptus*, where seed variability is great. *Eucalyptus* seed is often supplied as a mix of seed and chaff. Both between and amongst species, variability of seed to chaff ratios for a given batch can range from 7% to 20%. Further adding to this variability, counts of pure seed from different *Eucalyptus* species can range from 550 to 2200 seeds/g (J Jonson, 2007, unpublished data). Caution should therefore be applied when determining *Eucalyptus* seed input rates for direct seeding projects.

Row spacing is another key variable to consider with direct seeding rates. This variable affects the densities of established plants, their distribution and their subsequent development into plant communities. Seed is applied in a linear manner, so differences in row spacing equates to varying concentrations of per hectare seed rates applied within them. For example, a seed rate of 500 g/ha applied at a 5 m row spacing equates to 0.25 g/m, while the same rate applied at 3 m row spacing equates to 0.15 g/m. In this way, linear seed density increases as row spacing increases. This issue is magnified as seed rates per hectare increase. Row spacing is therefore a significant variable to consider in the context of seeding rates, desired plant density and the resulting structure of establishing vegetation.

Confirming this, quantitative assessments of a 70 ha direct seeding project from 2003 showed that linear stem densities across six plots had an average density of 4.21 (±0.40) stems/linear metre (J. Jonson, 2007, unpublished data). When dominated by Myrtaceous species this high stocking (site average stem per ha of 14 845.8; SE 1007.4) often results in vegetation with narrow and elongated growth. Such stem density counts are close to five times greater than that present in similar local remnant systems. In revegetation projects, areas between the seeded lines (inter-row) are often devoid of woody vegetation resulting in barren inter-row conditions, consistently demonstrated at sites of up to 20 years old (Fig. 5). Revegetation projects composed of wide spaced rows of high-density plants lack 'whole of site' structural complexity, and have been shown to demonstrate significant reductions in growth (England *et al.* 2006).

There are three main influences on practitioners' ongoing use of wide row spacings for direct seeding projects. These are availability of operational

Figure 5. Most conventional direct seeding implements are confined to single rows and create bare inter-row spaces >2 m. This photo from the West River catchment shows a representative example of farmland revegetation layout, showing a lack of colonisation 20 years after direct seeding.

funds, availability of suitable direct seeding equipment, and traditional approaches to revegetation site design. While each of these constraints to reducing row spacing are interlinked, limitations imposed by available direct seeding equipment and their associated scalping devices are significant. Scalping techniques used to displace residual chemicals and soil seed banks of agricultural weeds have been shown to be an effective method for improving establishment (Geeves *et al.* 2008). However, commonly available wide scalps (2.0 m), and their associated spoil widths, have been prohibitive to reducing row spacing below 3.0 m. Development of equipment with smaller scalping widths has occurred (Woodall 2006), however, single line seeding is still the dominant technique used. This single line seeding continues to constrain row spacing, as tractor and vehicle wheel base widths set minimum pass width. These variables, combined with funding constraints and traditional approaches to revegetation design, result in a continuation of revegetation projects with wide row spacings.

Stage 3. Development of new direct seeding equipment

A new direct seeding machine was developed to deliver the appropriate initial floristics (including distribution and density) and to move away from high stem densities and wide spaced linear rows (Figs 6,7). Drawing on a number of influences, the machine was designed to reduce row spacing, while also increasing the capacity to operate at a larger scale than previous projects. Modifications to a 20 ft (6.1 m) Great Plains no-till precision seeding agricultural machine were undertaken to transform it into a native plant seeder. Central to this design was a reconfiguration of row spacing. By positioning seeding row spacing at 1.4 m across the 6 m bar, five rows could be seeded simultaneously within one 7.0 m operational pass width (Fig. 7). This enabled a doubling of area seeded per hour. The original double-disc-opener precision seeding agricultural units were retained (Fig. 6), while the seeder box was modified to provide independent bins for each row. At the front of the machine a second bar previously used to mount agricultural coulter discs for knocking down wheat stubble, was now used to mount five mini-scalping units (Fig. 8). A contractor was employed to build mounting brackets with breakout capacity for each mini-scalp, also positioned on 1.4 m centres. The new direct seeding machine thereby enables a one pass operation, sowing seed mixes down the centre of five individually scalped low spaced (1.4 m) seeding lines.

Stage 4. Implementation – on-ground works in 2008

Following the development of the restoration map, the nine new vegetation associations, and a new direct seeding machine, 2008 saw the implementation of a 250-ha restoration project (Fig. 9).

To manage for agricultural weeds and Red-legged Earth Mite (*Halotydeus destructor*) in the lead up to seeding, a series of four different spray treatments were applied. Consistent with agricultural practices, weed control was used to retain valuable soil moisture (Carr *et al.* 2008), assisting

Figure 6. Agricultural precision placement seeder modified for sowing local native woody plants at Peniup. The design builds on a long history of direct seeding equipment development, influenced by many sources.

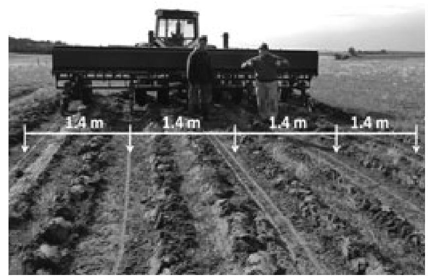

Figure 7. Seeding row spacings at 1.4 m centers allows for a 7 m 'one pass' operation which scalps and seeds five rows at once. Improved spatial coverage of seeded areas were achieved, along with a fifty percent reduction in operational costs.

Figure 8. The agricultural coulter bar, and five mounted mini-scalping units. The breakout assembly and mounts for each mini-scalp were developed by Danny ten Seldam.

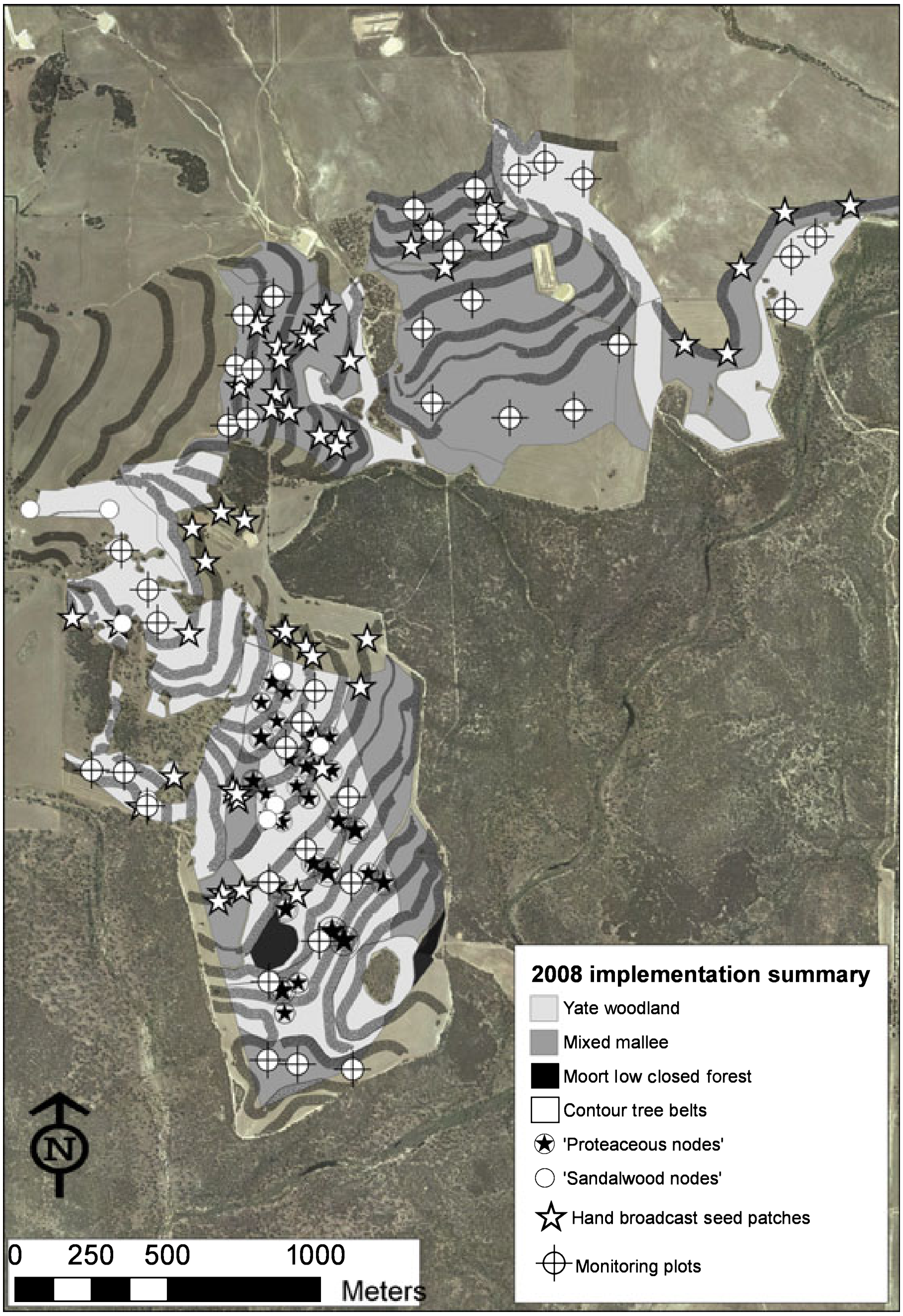

Figure 9. Map of 2008 on-ground works showing the nine vegetation association areas, locations of the contour tree belts, node plantings, hand broadcast seed sites and monitoring plot sites.

germination and establishment of new seedlings, while reducing summer mortality rates.

Building Seed Mixes

With vegetation associations defined, building individual seed mixes was now required. Firstly, a number of seed treatments were needed to assist with dormancy constraints. This included several different heat, scarification, smoke and gibberellic acid treatments for select species (details available from the author).

To address the knowledge gap on appropriate direct seeding rates (by species or genus), exact quantities of seed for each species were measured for every seed mix at Peniup. Documentation of these values, along with field-based measurements of what is established will provide seed rate guidelines for future projects with similar objectives. Seeding rates varied between soil landscape zones, and will be described in a separate paper.

Following the compilation of accurately measured seed mixes, calibration of machine 'flow-rates' for the direct seeding was required. Calibration of flow rates was undertaken over eight times throughout the project to ensure known deposition rates. Volumetric flow rates of seed and bulking agent (vermiculite) mixes were calculated for the machine settings to be on average 5.5 (±0.1) l/km. With a machine operational pass width of 7 m, this equated to an average deposition rate of 7.9 l/ha. High flow rates helped ensure consistent and uniform deposition. Prior to sowing, the seed was systematically mixed into the bulking agent in measured quantities to avoid the risk of irregular stratification and patchy distribution of seed within the bulking agent.

Direct seeding depth placement with double-disc-opener agricultural seeding units focused on a target depth of 5 mm. Seed applied on the soil surface can be predated by ants, and are at risk of desiccation if germination is followed by dry weather. Alternatively, seeds planted too deep can fail to push their emerging cotyledons to the surface. While a target depth of 5 mm was pursued, actual depth placement was likely to range from 0 to 20 mm for a number of reasons. Variability incurred from the aged precision placement seeding equipment, and differences in the scalp cutting depth over a wide range of soil types, requiring ongoing adjustment of disc depth throughout the project.

Using seedlings to manage risk

As some of the projects funds were generated through a carbon biosequestration contract from Mirrabella

Figure 10. An early photo of tree belt site preparation, which were established on the contour.

Lighting Company, it was critical to ensure reliable establishment of the main carbon producing species. While direct seeding has been demonstrated to be a more cost effective means to establishment, poor seasonal conditions can lead to poor results. To offset this potential risk, 93 000 nursery grown seedlings were planted throughout the project area. For each soil landscape zone, 30% of each area was allocated to the planting of these seedlings. A series of five row wide tree belts were established using a Chatfield planter. This machine implements a zone of improved conditions through a 2-m wide 'V' scalp, a shallow rip (200 mm), followed up with two opposed discs to provide a shallow mound. Using a laser level (10 mm accuracy), these tree belts were positioned to run on the contour (Fig. 10) to improve the capture and infiltration of scarce rainfall.

Complimenting broad brushstrokes with fine detail

When undertaking restoration works at scale there is an inherent pressure to approach implementation in broad terms through the application of standardised treatments. Using painting as a metaphor, the trend is to focus on broad 'brush strokes'. While broad patchiness is represented in native ecosystems, fine detail is present as well. To better reflect the complexity of the natural systems of the region, a number of fine scale treatments were implemented to improve the conservation and biodiversity outcomes.

To most effectively utilise seed batches of limited quantity, measured amounts of seed were hand broadcast in discrete patches at a number of specific locations. The establishment of these hard to collect species in confined patches is anticipated to concentrate flowering resources and attract pollinators, thereby enhancing pollen distribution and subsequent gene flow. By targeting specific locations, and recording GIS points, the success of these rare batches can later be assessed.

Knowledge about small quantities of seed was also built into seedling orders. For example, proteaceous seed is known to be difficult to collect and its yield is often low. Seed germination within this family can require a specific set of conditions hard to replicate in a direct seeding approach. To address these challenges, 5800 proteaceous seedlings were grown for the project. They were planted in mixes throughout the target areas in discrete locations termed 'proteaceous nodes' (Fig. 11). These nodes were composed of groups of seedlings ranging from 10 to 50 individuals planted in close proximity. The impetus for this approach was to create concentrated food sources for nectarivorous fauna, while increasing pollination and long-term plant species viability.

In 2009, eight 'sandalwood nodes' comprising a total of 130 potential individuals were also hand seeded. At each location two treated seeds from the hemi-parasitic Sandalwood (*Santalum spicatum*) were planted adjacent to leguminous hosts established from the 2008 direct seeding. In the future,

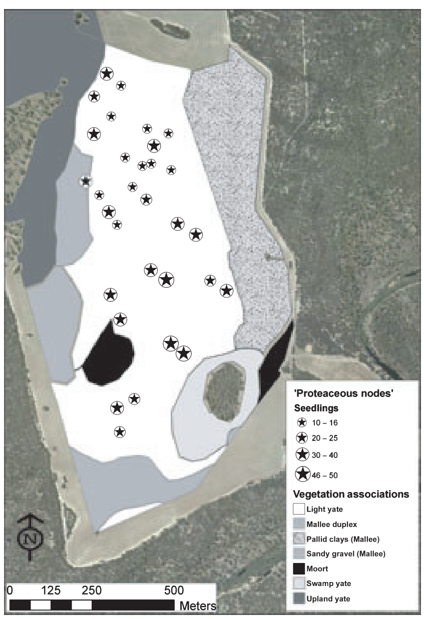

Figure 11. A map illustrating the spatial position of 'proteaceous nodes'; patches of 10–50 hand-planted seedlings established to increase the presence and distribution of key flora.

these sites can serve as resource-rich areas, providing valuable food sources for both frugivorous and insectivorous fauna.

This 'node' technique is unique in the context of restoration at large scales. It enables a finer level of detail to be added to broader treatments, increasing the richness of a re-establishing plant community. Further development of the approach can be used for establishing new populations of rare and threatened flora within large scale projects.

Monitoring and evaluation of initial results

Data collection

Quantitative information on species establishment from direct seeding rates was sought leading into this project; yet we were unable to find any local (or Australia wide) information available in the public domain to inform the development of appropriate seeding rates at either genus or species level. This information gap restricted our ability to best reconstruct vegetation communities of specific composition, density and structure. To address this gap, our on-ground works incorporated a rigorous data capturing exercise. Consistent deposition of measured seed rates, delivered across seven different soil/landform units, will provide an excellent opportunity for long-term monitoring and evaluation.

Previous reports on direct seeding have most often focused on the number of seedlings per linear unit. However, this approach fails to address row spacing, and fails to link the practice of direct seeding to the goal of reconstructing vegetation communities. In addition, measurements are rarely recorded at permanent locations over a number of years.

At Peniup, 42 permanent monitoring plots have been established across six different vegetation associations. This monitoring and evaluation has three main objectives:

1 Provide short-term data on the number of established seedlings for management reporting.
2 To review established plant counts with seed input rates, for developing improved seed mixes.
3 To chart the assemblage trends for each association over time.

Plots were established in line with the direct seeding contours with a plot width of 14 m. This captured two passes of the seeding machine (10 rows at 1.4 m). Plot length for the first 24 plots was 10 m, with 18 later plots having a length of 20 m. For each seeding row, a measuring tape was laid alongside it, and each seedling was recorded for species type and distance along the row. In this way, a spatially explicit map was created for each seedling (Fig. 12). Measurements taken can then map the spatial and temporal fate of each germinated seedling. This information can also be used to extrapolate the current trajectories of plant community structure and canopy cover. This method provides an opportunity to forecast the canopy area for the current mix of establishing vegetation, as demonstrated by Newbey (1985).

Applying a projected foliage cover (of ~20 years growth) to the plot data collected from four different vegetation associations (Fig. 13) illustrates the non-linear assemblage achieved with the new seeder. The resulting seedling distribution is both spatially diverse and random in pattern. There are both tightly spaced 'thickets' and non-uniform open areas, as sought in the restoration objectives. Observations from other local environmental

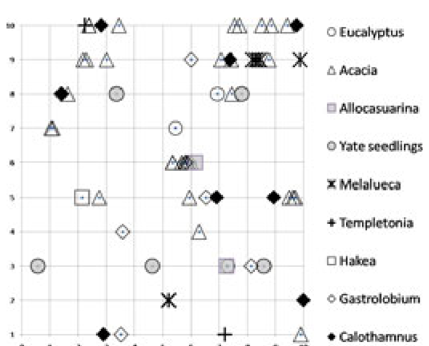

Figure 12. Plot data for the Upland Yate association (PEN 121). Monitoring in 42 plots over six vegetation associations, totalling 7980 m^2 in area, allowed for spatially explicit maps to be created of established seedlings.

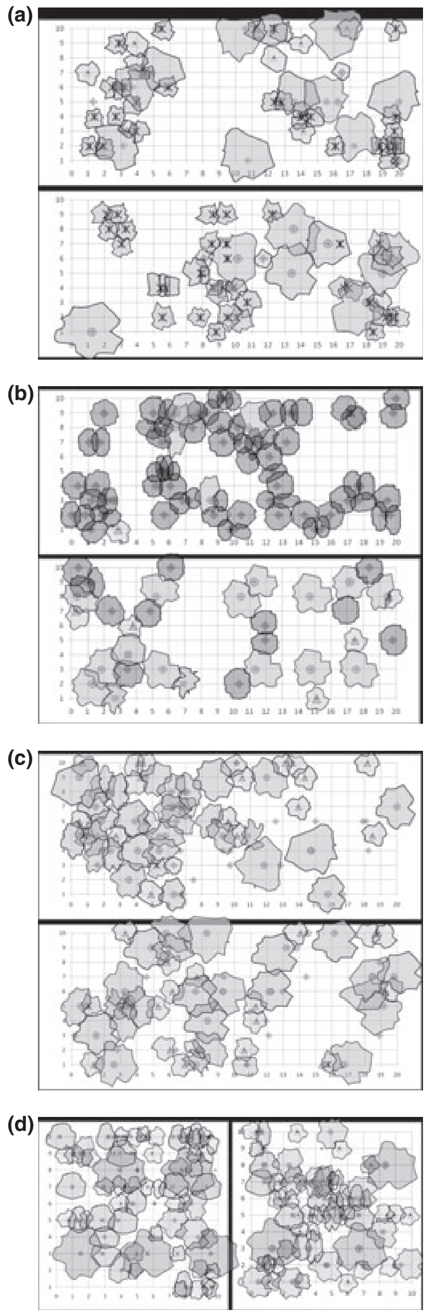

Figure 13. Plot data results and forecasted (~20 years) canopy areas for four vegetation associations: (a) Mallee Duplex (PEN133 & PEN134), (b) Gully (PEN137 & PEN138), (c) Pallid Clay (PEN144 & PEN142) and (d) Light Yate (PEN101 & PEN100).

Table 1. Preliminary mean seedling counts established from direct seeding and recorded in plots of measured associations (June 2009)

Vegetation association	Area (m^2)	Total	*Eucalyptus*	*Acacia*	*Allocasuarina*	*Templetonia*	*Melaleuca*	*Gastrolobium*	*Kennedia*	*Callistemon*	*Calothamnus*	*Hakea*	*Eremaea*	Other
Light Yate†	140	59.8	11.1	32.6	6.3	0.4	6.6	0.2	0.9	1.1		0.1		
Upland Yate (1)†	140	30.3	4.3	10.2	7.7	0.5	1.8	0.5		1.2	3.7	0.2		
Upland Yate (2)†	140	29.7	5.3	12.0	0.7	0.7	2.3	3.7		0.0	4.7	0.3		
Sandy Gravel (1)	140	45.8	12.5	27.3			1.5		3.7			0.2	0.7	
Sandy Gravel (2)	140	32.3	13.3	14.7			3.0		0.7				0.7	
Mallee Duplex	280	42.7	7.3	10.3			19.0						2.5	3.3
Gully†	280	55.7	3.0	7.7	1.0		0.3				37.0			
Pallid Clay	280	50.2	21.5	11.7			1.8	0.8			0.2	0.8		13.3

†Associations with supplemental seedlings planted within direct seeded areas (seedlings not included in count).

plantings have shown that open areas are often colonised by native grasses within 5–10 years. It is proposed that the diversity of structure and non-uniform distribution of the reconstructed system will provide a range of different of habitat types.

Preliminary densities

Over several monitoring efforts (December 2008, March 2009, June 2009) a total of 5700 m of seeding lines were evaluated, equating to a 7980 m^2 area. Within this area, 1905 seedlings were recorded. A minimum of three plots was established for each vegetation association. Plots were

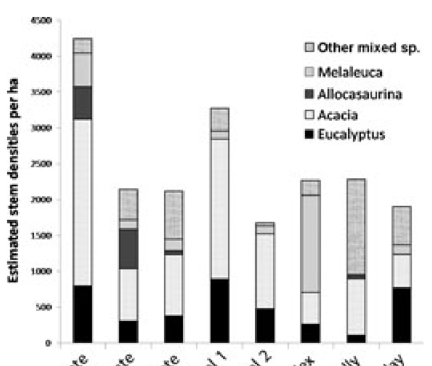

Figure 14. Average stem densities 1 year after seeding, extrapolated from plot data collected for each vegetation association measured. Seedlings were also hand planted in the Yate and Gully associations, but those counts have not been included in this chart.

positioned across the planting areas in a stratified random approach. Mean results of these plots, summarised by vegetation association groups, are shown in Table 1. These results refer to germinated seedlings that had survived through the first summer (hot and dry) season.

Calculations of average per hectare stem densities for each vegetation association are presented in Figure 14. Sufficient seedling counts were achieved in five out of six vegetation associations. Overstory stocking rates of 300 and 500 stems/ha were achieved for these Yate and Mallee systems respectively. Although measured establishment is on track to achieving goal densities, it is too early to make any definitive statements about these preliminary results. Further research is required to quantify the relationship between established seedlings and seed volume input (and/or individual seed counts). This analysis can included the influence of soil type on seedling establishment through direct seeding. With these permanent plots, long-term measurements on direct seeding, plant community assembly and carbon sequestration can be undertaken.

Preliminary floristics

Table 1 lists the primary genera successfully established through direct seeding at Peniup. They represent 71 out of the total of 110 species seeded. Given the scale of the establishment, it is expected that other species not captured in the 0.79-ha sampled area may have also established. It is also possible that some species may have longer post dormancy ripening processes and will germinate at a later date.

In terms of the distribution of these species, our preliminary results show that the initial floristics of the wide range of sites exhibit a high degree of correspondence with the target vegetation associations. For each system, there is generally a good representation of species from the main genera which are found in each of those native associations. For example, the sandy gravel mallee systems, are dominated by *Eucalyptus falcata*, *Eucalyptus thamnoides* and *Eucalyptus captiosa*, for the mallee overstory component, with *Acacia pulchella*, *Acacia gonophylla*, *Acacia varia* and *Kennedia prostrata* showing strong establishment densities for the understory component. In the mallee duplex system, tough mallees such as *Eucalyptus conglobata* and *Eucalyptus flocktoniae* have established, while a rich mix of the 10 different *Melalueca* species seeded have also come up, reflecting the health like assemblage of this native association. These initial results show a promising level of consistency with the native associations on which they are based.

Figure 15. Photo of Light Yate Vegetation Association showing both hand-planted Yate seedlings and the understory and mid-story species beginning to establish from direct seeding.

Similarly, the Yate systems have establishing representative understory's sparsely populated by *Acacia acuminata*, *Acacia cyclops*, *Allocasuarina huegeliana*, *Melalueca hamata* and *Calothamnus quadrifidus* as seen in their naturally occurring remnant systems. While it is too early to claim that all of the target communities are on a secure trajectory of recovery, the sites will continue to be monitored over time. It is envisaged that further interventions may be required to gain the full ecological benefits that these sites have to offer (Fig. 15).

Key lessons and conclusions

This project has adopted a number of simple principles, with results to date adding weight to their usefulness. The first is that large scale ecological restoration in a highly heterogeneous and species-rich landscape requires a big commitment to fine scale planning. In the case of this project, this approach was applied through the early development of a restoration map that defined local soil/landform units. This map then enabled us to match plant species to their preferred biophysical locations, with promising early results. This overall process aims to test whether a shift from mixed soup/shot gun direct seeding approaches, to the reconstruction of defined plant communities results in improved resilience and habitat value.

Another principle adopted early in the project is that detailed designs require sophisticated implementation. With the development of a new direct seeding machine, row spacing was reduced to 1.4 m. This allowed for a transition away from highly stocked linear belts of vegetation, to defined and well spaced heterogeneous plant assemblages. In addition, 31 'proteaceous nodes' and eight 'sandalwood nodes' were located within the broad associations to further provide resources for nectivorous and insectivorous fauna. Further research on the outcomes from these efforts will be used to evaluate the efficacy of these treatments. In the area of direct seeding, it is hoped that the detailed measurements taken of seed input rates may help further improve the capacity of practitioners to better re-create plant communities with representative species compositions.

A final principle adopted and implemented early in the project was that of sensitivity to initial conditions, where overcoming ecological thresholds is likely to be highly dependent on initial management decisions, helping to set a system on a desirable trajectory of recovery. This meant committing ourselves to extra effort in key areas of project planning and implementation. We believe that this has enabled us to counter the common perception that increases in the scale and speed of revegetation, is incompatible with improving the ecological quality and cost efficiency of such works. Project management for restoration is a challenging discipline. While we may not have met all the project's goals, we hope our initial successes will encourage other managers to develop multi-faceted approaches to avoid short-term tradeoffs, and seek multiple outcomes through improved planning and long-term goals.

Acknowledgements

Many thanks to: Keith Bradby for support throughout; Robert Lambeck, David Freudenberger, James Fitzsimons and Sam Crowder for comments provided on the manuscript draft; Craig and Peter Luscombe of Nindethana Seed for their helpful collaboration; Sam Crowder, Luke Barrett, Danny ten Seldan for help in implementation; Rachel Standish and Lauren Hallett for help monitoring; The Shell Reconnections Project; The Mirabella Light Company; The Nature Conservancy and The Thomas Foundation for provision of generous financial support for undertaking parts of this project and enabling the publication of this work. Many other practitioners and individuals in the region have made significant contributions to the state of knowledge in this field.

References

Bradby K. (2008) *GONDWANA LINK: A Landscape Scale Restoration Project in South-West WA. Global Restoration Network Report, 'Top 25' Ecological Restoration Projects in Australasia*. [Cited 25 Jan 2010.] Available from URL: http://www.gondwanalink.org/GLink_GRNreport.pdf.

Carr D., Rawlings K. and Atkinson P. (2008) Site preparation – moisture conservation. In: *Native Vegetation Management Tool*. FloraBank. Greening Australia, Canberra. [Cited 25 Jan

2010.] Available from URL: http://www.florabank.org.au/default.asp?V_DOC_ID=966.

Cramer V. A., Hobbs R. J. and Standish R. J. (2008) What's new about old fields? Land abandonment and ecosystem assembly. *Trends in Ecology and Evolution*. **23**, 2.

Deegan P. and Sanders A. (2008) *Functional Landscape Plan, Fitzgerald to Stirling Operational Area. Version 2*. [Cited 25 Jan 2010.] Available from URL: http://www.gondwanalink.org/Fitz-Stirling_FLP.pdf.

England J., Paul K., Falkiner R. and Theiveyanathan T. (2006) Rates of carbon sequestration in environmental plantings in north-central Victoria. *Proceedings From Veg Futures 2006 Conference*. 19–23 March, Albury.

Fazey I. and McQuie A. (2005) Appling conservation theory in natural areas management. *Ecological Management & Restoration* **6**, 147–149.

Geeves G., Semple B., Johnston D. *et al*. (2008) Improving the reliability of direct seeding for revegetation in the Central West of New South Wales. *Ecological Management & Restoration* **9**, 68–71.

Hobbs R. and Harris J. (2001) Restoration ecology: repairing the Earth's ecosystems in the new millennium. *Restoration Ecology* **9**, 239–246.

Hopper S. D. and Gioia P. (2004) The Southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecological and Evolutionary Systems* **35**, 623–650.

Krauss S. L. and He T. H. (2006) Rapid genetic identification of local provenance seed collection zones for ecological restoration and biodiversity conservation. *Journal for Nature Conservation* **14**, 190–199.

Newbey K. R. (1979) *The Vegetation of Central South Coastal Western Australia*, Masters Thesis, Murdock University, Perth.

Newbey K. R. (1985) *Fire Ecology Study of the Marningerup Section, Fitzgerald River National Park, Western Australia*. Report for Department of Conservation and Land Management, Perth.

Suding K. N., Gross K. L. and Houseman G. R. (2004) Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* **19**, 46–53.

Temperton V. M. and Hobbs R. J. (2004) The search for ecological assembly rules and its relevance to restoration ecology. In: *Assembly Rules and Restoration Ecology-Bridging the gap Between Theory and Practice* (eds V. M Temperton, R. J. Hobbs, T. Nuttle and S. Halle), pp. 34–70, Island Press, Washington D.C.

Whisenant S. G. (1999) *Repairing Damaged Wildlands: A Process-Oriented, Landscape-scale Approach*. Cambridge University Press, Cambridge.

Woodall G. (2006) At last, a direct seeder that sows quickly and precisely. *Australian Forest Grower Spring* **29**, 42.

Summary **Large scale ecological restoration in a highly heterogeneous and species-rich landscape requires big commitment to fine scale planning. In the southwest of Western Australia, in the Fitz-Stirling area of Gondwana Link, the Peniup Restoration project aimed to improve on such works. A multi-faceted approach was employed to re-establish a self-replicating biologically diverse plant system, ecologically informed in its design and consistent with the heterogeneous mosaic of plant associations found in the surrounding landscape. Outcomes from the project included a 950-ha restoration map composed of nine newly developed soil landscape/vegetation associations. A new 6 m wide direct seeding machine was developed to improve delivery and spatial configuration of establishing plants. These two developments were put to the test in 2008 through a 250 ha biodiverse carbon-funded restoration effort. This paper summarises the approaches used and initial results of those works.**

