doi: 10.1111/j.1442-8903.2010.00547.x

Expanding horizons for herbaceous ecosystem restoration: the Grassy Groundcover Restoration Project

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Thirteen experimental sites throughout regional Victoria demonstrated that direct seeding species-rich herbaceous assemblages on ex-agricultural sites is a feasible means of reconstructing grassland or herbaceous understorey for biodiversity conservation

Figure 1. An image of the type of agricultural setting in which the Grassy Groundcover Restoration Project (GGRP) was undertaken. Farm sites such as this served as locations where the GGRP tested its site preparation and seeding methods. Our goal was to reconstruct complex grassland or grassy understorey (reflective in composition and structure to local remnant communities) on agricultural sites within fragmented landscapes.

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Introduction

The Grassy Groundcover Restoration Project (GGRP), a partnership between Greening Australia (Victoria) and the University of Melbourne, is a restoration and research initiative undertaken across southern, central and western Victoria, Australia. The project has a range of objectives including the following: to establish demonstration sites for herbaceous ecosystem restoration; to test the effectiveness of direct sowing of multi-species seed mixtures (representative of locally occurring remnant communities) on agricultural sites (Fig. 1); and to examine the use of seed production techniques to secure supplies of high-quality seed from a broad range of species.

Grasslands in southern Australia are among the most endangered of Australia's ecological communities (Kirkpatrick *et al.* 1995), and species-rich herb layers are a diminishing component of endangered grassy woodlands (Benson 1991). In Australia, there has been limited opportunity to trial large-scale reconstruction of herb-rich grasslands and grassy understoreys. Revegetation projects in Australia's cleared agricultural lands have traditionally focused on the reinstatement of trees and shrubs, largely sidestepping the difficult task of establishing the herbaceous layer (Coor 2003). Many practitioners have assumed that restoration of complex herbaceous layers is either impracticable on larger scales or more achievable at a later stage when increasing woody cover reduces grass and weed competition. The GGRP tested the first of these assumptions, inspired by common agricultural techniques (such as, fallowing, preparing seedbeds and reducing weed loads), the results of meadow and prairie restoration in the Northern Hemisphere (e.g. Piper & Pimm 2002, Pywell *et al.* 2002; Sheley & Half 2006) and smaller-scale Australian herbaceous studies (e.g. McDougal and Morgan 2005; Smallbone *et al.* 2007; Gibson-Roy *et al.* 2007b).

The project emphasized experimental design and regular monitoring to ensure that the objectives of the on-ground work would be met and that the project results would inform future practice.

The imperative for herbaceous restoration

Prior to European settlement, temperate lowland native grasslands and grassy woodlands occupied several million hectares of inland south-eastern Australia (Benson 1991; Kirkpatrick *et al.* 1995). Within the three main bioregions where the GGRP was conducted, land use over the last 150 years has reduced the area of intact native vegetation to nil on the Victorian Volcanic Plains and the Central Goldfields and to <1% in the Wimmera (VEAC 2010). Surviving diverse herbaceous communities are highly fragmented and mostly small (<5 ha), leaving them vulnerable to extinction.

Obstacles to the natural recovery or expansion of remaining herbaceous communities include a lack of source populations and/or intense competition from dense swards of exotic species, particularly where soil nutrients have been elevated by fertilizer application, primarily superphosphate (Dorrough & Scroggie 2008). Reconstruction may be one of the few practical ways of increasing the quality and/or extent of these communities.

Although native trees and shrubs have been successfully direct-seeded in Australia for some time (Coor 2003), restorationists have been reluctant to include grasses and forbs in these programmes. In addition to a lack of reliable seed supplies (Mortlock 2000), the fruits and seeds of many herbaceous species do not flow well through traditional agricultural seeders (Coor 2003; Morgan 2005). Also, early studies of the direct sowing of herbaceous species reported low and unpredictable emergence and high rates of seedling mortality (e.g. McDougall & Morgan 2005). However, other studies that focused primarily on grasses (with some selected forbs) found particular species could be used successfully in restoration programmes (Huxtable & Whalley 1999; Windsor & Clements 2001; Cole *et al.* 2005; Gibson-Roy *et al.* 2007b).

Other studies improved our understanding of the dynamics operating within herbaceous communities, particularly focusing on community structure and function and on the links between soil nutrients and native and exotic competition (Lunt 1997; Prober *et al.* 2002; Prober & Thiele 2005; Gibson-Roy *et al.* 2010). Their findings highlighted several key factors for the successful restoration of complex herbaceous communities. These include securing sufficient seed, creating suitable recruitment niches, developing seeding technology, managing elevated nutrients and controlling weed competition, creating functional communities and managing sites to preserve diversity.

A General Overview of the GGRP Programme

Start-up and finding the right people

With National Heritage Trust (NHT) funding secured for 3 years, a steering committee was established to facilitate proper governance. A technical panel of plant scientists (with experience in experimental design, herbaceous systems, population biology and statistical analysis) advised on the design and monitoring of experiments. Regional meetings and advertising located over 40 landholders and mangers prepared to host 1 ha experimental sites. Selection criteria were developed focusing on historical and current land use, site security and tenure, access to local remnants and seed resources, and local capacity. Thirteen sites were chosen, nine on private and four on public land (Fig. 2). Participants signed memoranda of understanding, agreeing to preserve and manage their sites in consultation with project staff and to provide access for long-term monitoring (e.g. 10+ years).

Defining seeding mixes, harvest zones and harvest protocols

Ecological Vegetation Classes (Department of Natural Resources and Environment 2010) were used to define the community being reconstructed (e.g. plains grassland, plains grassy woodland, grassy dry forest) and to identify regional seed collection sites. Gibson-Roy *et al.* (2009) found that high levels of plant diversity (species and functional) could be established early in the grassland restoration cycle. These and other authors (e.g Prober & Thiele 2005; Sheley & Half 2006) argued that species and functional diversity should guide the restoration of functional and resilient herbaceous communities. For seeding mixes, the GGRP targeted a diverse range of species and functional groups (C3 grass, C4 grass, legume, geophyte, chamaephyte, hemicryptophyte, therophyte)

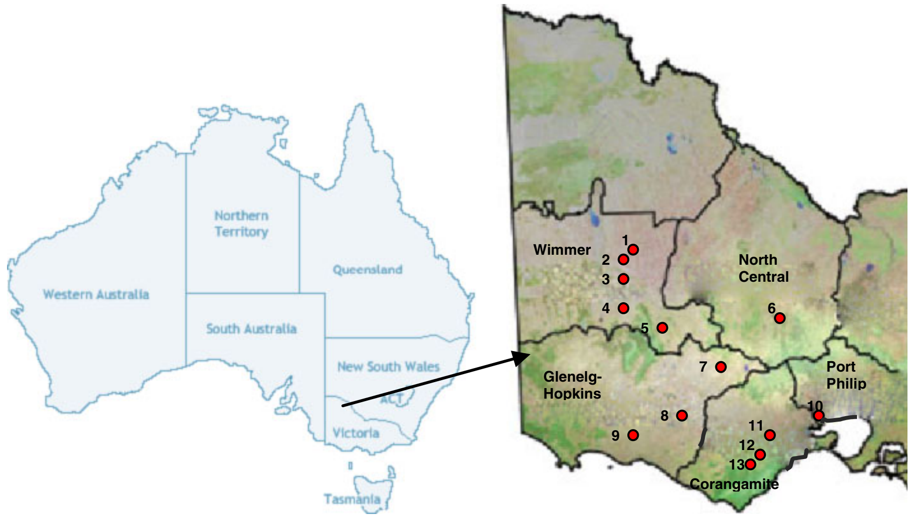

Figure 2. A map of Australia and central and western Victoria where the Grassy Groundcover Restoration Project was undertaken. The project was conducted within four Victorian Catchment Management regions. Thirteen sowing sites were located across these regions, three in Corangamite (13 – Beeac, 12 – Colac, 11 – Winchelsea), three in Glenelg-Hopkins (7 – Chepstowe, 8 – Chatsworth, 9 – Hamilton), one in Port Philip (10 – Werribee), one in North Central (6 – Ravenswood) and five in the Wimmera (4 – Laharum, 3 – Longerenong, 5 – Moyston, 2 & 1 – Minyip).

(Tremont & McIntyre 1994). Different and distinctly local floras were sown across the project with between 40 and 100 species at each site, comprising all functional groups. Altogether, seed from more than 200 species was harvested for inclusion in sowing mixes and/or seed production.

Identifying high-quality seed sources is among the greatest challenges for restorationists working in highly fragmented landscapes (Broadhurst *et al.* 2008). Most guidelines for seed collection advocate that seed of local origin or provenance is best (Cole *et al.* 1999), while others question the strict adherence to 'local is best' based on theoretical and practical considerations (Wilkinson 2001; Broadhurst *et al.* 2006, 2008; Bischoff *et al.* 2010). To define harvest zones from within larger geographical areas (such as the Victorian Volcanic Plains and the Wimmera Plains), the project considered current and historical distributions and connectivity between populations of species within an EVC. The aim was to reduce the risk of creating inbreeding populations, to increase species diversity and the amount of seed available, to improve the adaptive potential within the reconstructed community and to preserve regional identity (Broadhurst *et al.* 2008; Bischoff *et al.* 2010).

Seed harvest zones were defined within each region, linked to specific experimental sites. Within a harvest zone, collectors matched source and receiving sites on the basis of soil type and topography (Cole *et al.* 1999). Most forb species were collected within 30 km, and grasses within 50 km, of a seeding site. Collectors targeted every herbaceous species present and producing seed, ensuring representation from all functional groups. For most species, seed was collected from 50 to 500 plants per population. For large populations that were mechanically harvested, estimates of harvest size would routinely exceed 5000 individuals. Seed was collected across the source population and over the entire season. Collectors aimed to avoid conscious or unconscious selection by working along transects to reduce relatedness. Seed collectors were paid a flat daily rate rather than by the amount of seed they harvested so that they could focus on collection protocols rather than the need to collect large volumes.

Grassy Groundcover Restoration Project staff worked closely with seed collectors across each of the sowing zones to improve native herb recognition and harvest skills. Regular workshops and technical newsletters were used to disseminate information and increase skill-sets (Grassy Groundcover Gazette 2006/10). The GGRP established a highly proficient and dedicated group of people across western Victoria, with a very high level of expertise in the harvest of seed from this flora. Relevant permits and approvals for collection were obtained in all regions.

While for some species, in some zones, in some years, wild collections provided adequate seed supplies (e.g. Wallaby Grasses – *Austrodanthonia* spp., Spear Grasses – *Austrostipa* spp., Common Everlasting – *Chrysocephalum apiculatum*, Lemon Beautyheads – *Calocephalus citreus*), this was not true for most species. The task of securing appropriate seed quantities from such a range of species and locations was daunting, given that in Victoria, traditional seed suppliers typically offer only small quantities of seed from a small range of herbaceous species. Therefore, to meet the seed requirements, the project funded regionally linked seed production areas (SPAs) (Gibson-Roy & Delpratt 2005; Cole and Johnston 2006, Holmquist 2010).

Seed Production Areas (SPAs)

Seed production was based on the 'box' system developed at Burnley College for grassland reconstruction research. The crops comprised seedlings grown at high densities in containers, with the concept being modified and expanded over the life of the project, to include carefully managed in-ground beds (Fig. 3). Native plant propagators from the various seeding regions were contracted to establish and manage SPAs for one or more sites within the same harvest zone.

Seed production area managers had sound knowledge of seed propagation

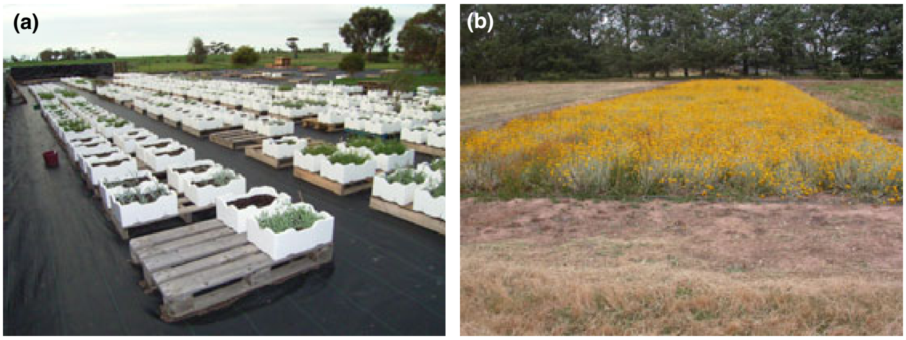

Figure 3. (a & b) Examples of plants grown for seed in the box and in-ground systems. (a) A range of herbaceous species grown in high-density, above-ground plantings; (b) In-ground crop of Common Everlasting (*Chrysocephalum apiculatum*).

and the facilities to grow plants successfully. GGRP staff worked closely with managers during the establishment and operation of each SPA. The SPAs produced large quantities of quality seed from numerous species indigenous to each harvest zone or region. Wild collection protocols aimed to capture quality and genetic traits within each harvest zone, and similar protocols were established to increase the chance that these features would be preserved through the seed production phase. In practice this meant appropriate mixing and subsampling of wild seed-lots when propagating production crops, avoidance of selection bias when pricking-out seedlings and harvesting seed from production crops, and harvesting over the whole fruiting period. Production populations contained as many individuals as possible (between 100 and 1000 individuals) given space and resource considerations. To further lessen the potential for genetic bottlenecking in the seed production phase, plants were only grown in production for two harvest seasons before new genetic material was introduced from wild populations.

Most of the 200 herbaceous species grown in the SPAs were readily propagated from seed and suited to the intensive, containerized and in-ground production systems. Establishing SPAs reduced the collection pressure on remnants, simplified seed harvest and produced reliable quantities of weed-free seed at times when field sources were severely impacted by drought and/or other events (inadvertent burns, grazing, and predation) (Gibson-Roy & Delpratt 2005; Cole & Johnston 2006). Also, under SPA conditions the period of seed-set for most species was extended through summer and into autumn (when plants in remnants had become dormant).

During 2006 and 2007, the seven GGRP SPAs produced a total of 92 kg of seed from approximately 200 species (primarily forbs). Only a tiny fraction of this volume and species range would have been available from wild populations or from seed banks. Their establishment and operation were affordable and technically straight forward, producing seed volumes without which the seeding goals of the project could not have been met. They also increased the knowledge of these species, their propagation and growth needs and techniques required to produce seed. The SPAs and the skill and knowledge of their managers now represent a considerable resource in the sowing regions, each capable of supplying high-quality seed in quantities and species range previously unheard of for herbaceous restoration.

Assessing seed quality

The effectiveness of restoration activities can depend heavily on the quality of seed used (Mortlock 1999). For this reason, the GGRP established a testing regime for seed used in each and every sowing mix. Purity assessment was used as the base testing protocol. This aimed to determine the percentage by mass of the seed-lot that was pure, filled seed of the species, the percentage by mass of impurities of other species seed (e.g. weeds) and the percentage by mass of inert matter (as seed was to be sown complete with some stems, seed appendages and seed coverings). If purity testing highlighted particular issues with a species seed-lot (such as very low fill of desired seed), secondary cabinet germination or chemical viability tests were conducted. This testing programme allowed an important understanding of the seed characteristics at the time of sowing and provided project staff an opportunity to more rigorously scrutinize field emergence. For example, seed testing information made it possible to include seed quality in an analysis of field emergence patterns (good or poor) rather than attributing them solely to post-sowing factors such as rainfall, temperature or predation. Seed testing findings were routinely disseminated in GGRP newsletters and at restoration forums and in technical journals (e.g. Grassy Groundcover Gazette 2006/10; Hall *et al.* 2006).

Pre-treatments and Seeding at the Restoration Sites

Soil testing was undertaken at each site to determine soil texture, colour, pH, nitrogen, phosphorus and electrical conductivity – as GGRP seeding sites had a variety of prior land-use histories. Three sites were situated on ex-cropping land with high soil nutrient levels, and because of cultivation history, deep weed soil seed banks. Nine were situated on lands converted to introduced perennial pasture where soil nutrients were typically lower than cropped sites, but soils had been fertilized periodically with superphosphate. Weed seed banks at these sites were shallower than on the cultivated sites. The one roadside reserve site was dominated by the exotic grass Phalaris (*Phalaris aquatica*). Nutrient levels at this site were also elevated in comparison with reference communities because of nutrient run-off from adjoining pastures and deposition of nutrients from stock movement. At all sites, native grassland species were either absent or represented by a few common species in very low numbers.

Before seeding at any site, a number of site preparation actions/treatments were tested experimentally (P. Gibson-Roy 2010 unpubl. data), which will be reported in detail at a later date.

For example, the GGRP investigated pre-sowing weed management techniques (previously trialled at another location and reported in Gibson-Roy *et al.* 2010) that aimed to exhaust or physically remove weed loads, or to reduce the competitive capacity of emergent/colonizing weeds. At each site, two soil preparation treatments were applied. Sowing areas were treated either with 1, 2 or 3 years of herbicide management in tandem with periodic shallow cultivation, or scalped to 100 mm (and shallow tilled) to remove or reduce the weed seed bank and lower nutrient levels.

Annual sowings were undertaken at each site between the years 2005 and 2007. These were also experimentally monitored, for reporting in a future paper. In year one (prior to the establishment of SPAs), only small quantities of seed were available from field collections, resulting in only relatively small areas (48 m^2) being sown at each site. For that year, the plots were hand sown onto lightly tilled beds and gently pressed to ensure good seed–soil contact. After the availability of larger quantities of seed from the SPAs, however, larger (4000 m^2) areas were sown in each of the following 2 years, using a GGRP modified seeder (Fig. 4).

The GGRP modified seeder

Cleaned seed can be sown using agricultural pasture drill seeders (Morgan 2005; Yurkonis *et al.* 2010) or through modified tree and shrub seeders (Coor 2003). Seed is commonly separated into hoppers holding ‘heavy’ or ‘light’ species and fed through tubes

Figure 4. The Grassy Groundcover Restoration Project seeder in action. Seed is sown onto cultivated bed (developed by the seeder) then lightly covered and pressed into the soil.

depositing it at designated depths in single or multiple rows, then press-wheeled into the soil. However, when uncleaned seed is fed through tubes (gravity or air assisted), seed appendages and associated chaff can cause blockages (Coor 2003; Morgan 2005). To save the cost of seed cleaning and because seed coverings and attachments have evolved to protect embryos and facilitate seed germination and seedling establishment, the decision was made to use uncleaned seed.

Various machines were assessed that would allow seed to be broadcast in its uncleaned state. Fertilizer spreaders have been used but are unreliable under windy conditions, present difficulties with seeding rate calibration and require a separate cultivation of the ground surface, increasing fuel and labour costs (Morgan 2005). Instead, the project investigated machinery used in the landscaping and turf industries. A machine used to aerate and de-compact soils in urban parks and sporting grounds (AERAvator®) proved ideal for seed bed preparation. Banks of tines oscillating on offset bearings fractured the soil profile, creating a good seedbed the width of the machine (1.5 m). A traditional tube-feed seed-hopper was mounted on the machine and modified to improve the flow of the seeding mix. All tubes were removed and the mix was drawn through the base of the hopper by an adjustable rotating bar so that it fell as a 1.5-m-wide curtain onto the prepared seed bed (Fig. 4). A mounted rake and roller lightly covered the seed and pressed it into the soil. Seed flow rates and tractor speed could be adjusted to achieve accurate sowing rates. The seeder was effective on a broad range of soil types from sandy loams through to heavy basaltic clays. To improve the flow of the seed mix, a range of bulking agents were tested including rice hulls, sawdust, vermiculite and washed river sand. Sand was the most cost-effective, easily sourced and suitable medium for carrying the seed.

Timing and season of seeding

In native grasslands in the winter rainfall zones of south-eastern Australia, most seed dispersal occurs during summer and autumn. This is followed by a flush of germination following the autumn break (the first rains after summer) (Morgan 2001). Based on these observations, GGRP sowings were initially scheduled to occur following autumn breaks. However, during the 3 years of sowings, there was not one clearly defined autumn break across the sowing regions. Unwilling to ‘dry-sow’, we delayed seeding until spring in the expectation that winter and spring rains on fallowed paddocks would provide sufficient soil moisture for germination and establishment of the sown mixes when soil temperatures began to rise. Fallowing also allowed management of winter and early spring weed growth. Therefore, based on the broad establishment success of seed-mixes sown in the spring of 2005, sowings in 2006 and 2007 also took place in spring. A total of 39 separate sowings were conducted across the thirteen sowing sites from 2005 to 2007. Hot dry summers with episodic rainfall were typical across all regions following sowings.

Seed mixes and rates

Site-specific seed mixes typically comprised between 40 and 100 species. Most harvested material (grasses and forbs) consisted of a combination of stem, fruits, coverings, appendages and seed. Rather than clean each species to pure seed (and remix as seed mixtures), a mulcher (Masport 6.5 HP petrol shredder) was used to process all harvested material to reduce it to a seed and chaff mix. In addition to saving the time and cost of cleaning seed, this method had the added advantage of retaining the species' appendages and coverings, which may assist seed burial and in some cases help retain dormancy (Cole *et al.* 2004). Purity testing revealed that the average percentage of pure seed in chaff (for all sites and across all species) was 39% (±2 SE). For the dominant grasses, which formed the major proportion of mass in mixes, the average percentage of pure seed in chaff was 29% (±2.5 SE). Because irregular rainfall patterns across at least some of the sowing regions were expected, no dormancy breaking techniques such as de-husking or the application of plant growth regulators, heat or smoke were imposed on seed-lots used in the experiment.

Sowing rates at each seeding event varied from site to site and from year to year, being linked to seed availability from field and production sources (requiring that results to be related to sowing rates for each site). In general, rates of between 5 and 11 g/m^2 were applied at the 39 sowings. These rates are broadly consistent with those applied in meadow and prairie restoration (e.g. Oliver & Anderson 1998). The sowing rate for each species was loosely tied to its abundance (and seed-set) in reference populations. Where SPAs enabled the production of suitable seed volumes, the seeding rates for particular species (e.g. threatened species) were increased.

General Vegetation Responses

Floristic results

For all sowings, emergence and survival patterns were carefully monitored. Plant counts and percentage vegetative cover for both sown and weed species were monitored each month for 5 months following sowing. These measures, and above-ground biomass, were made again at 12, 24 and 36 months after each sowing. Although detailed results will be presented in a future paper, a wide range of species successfully established at each site, totalling approximately 200 species across all sites. The total included 20 grass genera (represented by 48 species), 74 forb genera (132 species), and 10 sub-shrub genera (15 species) (See Appendix S1). Over all 3 years and the 39 sowings, early plant counts (up to 500 plants/m^2) typically declined over time to plant densities and structural composition comparable with those observed in the reference remnant communities (an average of 50 adult plants/m^2) (Fig. 5). In the shorter term (3–5 years of post-seeding), of the approximately 200 species sown in various combinations across the 13 sowing sites, 80% had established as sown populations consisting of a few, to many, individuals on at least one site. Monitoring indicated that in scalped plots (n = 130) vegetation composition, structure and quality have largely been retained in the years following seeding and into the management phase. Conversely, composition, structure and quality have declined markedly in non-scalped plots (n = 130) (Table 1). Among those that established were locally, regionally and nationally threatened species. Several GGRP sites now represent new (and potentially viable) populations of endangered species (e.g. Button Wrinklewort – *Rutidosis leptorrhynchoides* Hoary Sunray – *Leucochrysum albicans* subsp. *albicans* var. *tricolour*, and Yam Daisy – *Microseris lanceolata*). Indeed, through the utilization of SPAs leading to increased seed volumes, several sites feature populations of threatened species which exceeded the size of the source wild populations.

Germination was staggered over the 3 years and reflected the biology of the species and levels of summer rainfall. Annual rainfall was below the

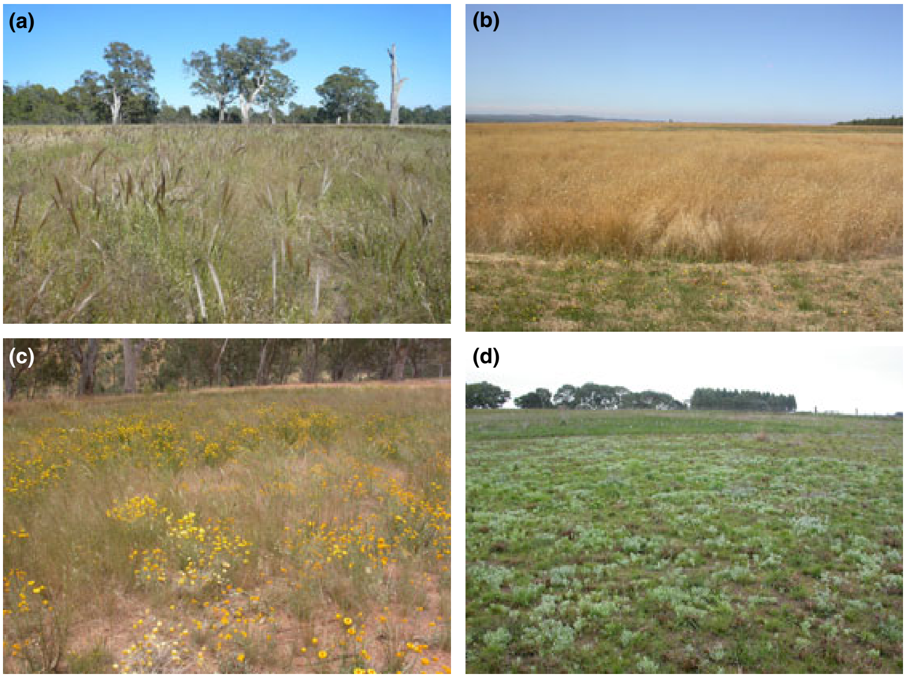

Figure 5. (a–d) Examples of diverse herbaceous communities established at various sowing sites (all on scalped areas). Each is dominated by native species with low weed cover and all closely resembles the compositional and structural characteristics of their relevant reference communities. (a) – Laharum, (b) – Chepstowe, (c) – Ravenswood, (d) – Hamilton.

Table 1. Comparisons of mean values on 2000 m^2 scalped and non-scalped plots for plant numbers (per m^2), biomass (g/m^2) and percentage cover after 3 years. All on plots were sown with a mechanical seeder in 2006. Identical seed mixes were sown on scalped and non-plots at each site, but mixes varied between sites

Measure	Category	Scalped	Non-scalped
		Mean (SE)	Mean (SE)
Plant Number per m^2	*Sown native*	52 (3.2)	18 (2.4)
	Grass	40 (4.4)	15 (1.6)
	Forb	12 (3.2)	2 (0.4)
	Non-sown exotic	37 (9.6)	197 (42.0)
	Grass	20 (4.4)	119 (26.4)
	Forb	20 (5.6)	78 (22.4)
Plant Biomass (g) per m^2	*Sown native*	207 (35.6)	119 (44.4)
	Grass	173 (28.8)	118 (44.8)
	Forb	34 (11.6)	5 (3.2)
	Non-sown exotic	67 (26.4)	382 (73.2)
	Grass	36 (19.6)	256 (77.2)
	Forb	29 (16.8)	126 (34.0)
	Total – sown native & non-sown exotic	272 (43.2)	504 (75.2)
Vegetative Cover %	*Sown native*	38 (5.6)	14 (3.3)
	Non-sown exotic	13 (3.8)	65 (5.0)
	Bare earth	49 (6.1)	21 (15.4)

historical averages in all sowing regions in each year from 2005 to 2007. At some sites, in some years, insufficient summer rainfall resulted in high seedling mortality (e.g. North Central & Wimmera regions – Fig. 2). With sufficient summer rainfall, a large proportion of early germinants survived (e.g. Corangamite and Glenelg-Hopkins regions – Fig. 2). Interestingly, at many of the dry sites where higher levels of mortality were recorded, many native seedlings persisted as tiny individuals. Excavation of sample plants revealed that they had developed deep roots, rather than above-ground growth. As seasonal conditions became more favourable, their above-ground growth expanded rapidly.

Each year, a range of species emerged in the autumn that followed sowing (and even through to spring). Certain species remained in the seed bank for 2 or 3 years before emerging (e.g. Mat-rush - *Lomandra* spp. and Flax Lily – *Dianella* spp.). This spread of germination was consistent with early laboratory experiments (Gibson-Roy *et al.* 2007a) that tested the fresh seed characteristics of 64 grassland species and found one-third germinated readily, one-third germinated at moderate rates and one-third remained un-germinated (but largely viable).

Weed control

Monitoring of weed numbers, vegetative cover and biomass, combined with soil testing, revealed soil scalping to be very effective in removing the soil weed bank and lowering soil nutrients (phosphorus and nitrogen) thereby reducing competition from weeds. Most interesting was the finding that neither 1, 2 or 3 years of repeated traditional weed control (cultivation combined with chemical control) reduced weed loads (numbers and biomass) to the same extent as scalping (Table 1 & Fig. 6). This outcome is consistent with other studies comparing scalping with traditional weed control techniques (e.g. Rasran *et al.* 2007; Gibson-Roy *et al.* 2010). Many restorationists dismiss scalping as unmanageable at scale and uneconomic. The cost of a road grader, however, is relatively low ($120-$150 per h) and scalping costs about $3000 per ha. If the goal of a restoration programme is to establish a diverse herbaceous community, traditional weed control (materials, machinery, labour) can amount to between $500 and $1000 per ha per annum. Scalping reduced this requirement and does represent an economic alternative. The micro-effectiveness of scalping was dependant of the skill of the operator, variations in topography and the management of these factors.

Soil tests of adjoining non-scalped and scalped areas revealed that at most sites, phosphorus levels dropped from an average of 26 to an average of 14 mg/kg leaving them similar to those of reference communities [<20 mg/kg (P. Gibson-Roy, 2010 unpubl. data)] while nitrogen levels in scalped areas were reduced by half or more in comparison with non-scalped areas. Low P levels appear to have aided the persistence of subdominant native species, and reduced nitrogen levels restricted the dominance of grasses (weed and native). The depth of an effective scalp is very much dependent on site history. Soil should be tested at various depths within the soil profile prior to any seeding programme so that the ideal scalp depth (in terms of nutrient characteristics) can be determined.

Moving scalped topsoil offsite was avoided to reduce costs. Topsoil at the GGRP sites was rowed into long thin mounds adjoining plots (100 m × 1.5 m × 30–50 cm). These mounds typically subsided over time to <30 cm. Because this nutrient and weed seed-rich burden had the potential to become a source of weed invasion, these areas were periodically sprayed with herbicides and over time have been colonized by native species from the plots (particularly grasses). In later years at other GGRP sites sown using similar methods, the topsoil has been spread even more thinly a short distance from the scalps (e.g. 2 cm × 15 m × length of plot) effectively top-dressing areas that are then sown only to mixes of native grasses. This has allowed control of broadleaf weeds with selective herbicides, while employing seasonal slashing and

Figure 6. (a & b) Areas within two 2000 m^2 plots at the Ravenswood site, one scalped (a) and one non-scalped (b). Both were sown with the same native seed mixture. Plot 'a' shows open and herb rich vegetation dominated by native species. Plot 'b' had been treated with 3 years of herbicide and cultivation prior to seeding. It is now dominated by a suite of exotic pasture grasses including Rye and Bromus Grass and is almost completely devoid of any sown native species.

'spray topping'to control some weed grasses as they appeared.

Reproduction and habitat development

Earlier studies of seeded grasslands noted an apparent failure to produce reproductive adults, precluding subsequent increases in density and/or expansion by natural recruitment (e.g. McDougall & Morgan 2005). In the 3 years following annual seeding of GGRP sites (i.e. following flowering and seed-set), plots were reviewed for evidence of natural recruitment. This was verified by the emergence of seedlings in un-sown areas (walkways between Year 1 plots, and in large 'recruitment zones' adjoining Year 2 and 3 sown areas) and as masses of seedlings close to adults (Fig. 7). Some short-lived species such as the Hoary Sunray (*Leucochrysum albicans*) or New Holland Daisy (*Vittadinia* spp.) produced many seedlings, while longer-lived species such as the Common Everlasting (*Chrysocephalum apiculatum*), Spur Velleia (*Velleia paradoxa*) and Chocolate Lily (*Arthropodium strictum*) produced fewer offspring. Other species such as Sweet Hound's Tounge (*Cynoglossum suaveolens*) expanded their range clonally.

Another encouraging finding was high levels of native plant and animal colonization within sites post-establishment. Many native trees (eucalypts and acacias) reappeared within swards in the woodland sites, and birds, mammals, amphibians and reptiles were routinely observed feeding, sheltering or nesting across all sites (Fig. 8). Formal surveys showed a range of native invertebrates colonizing these reconstructed communities and preliminary investigations of plant roots indicated the presence of structures associated with functioning arbuscular mycorrhiza. These observations indicate functionality on sites at other trophic levels.

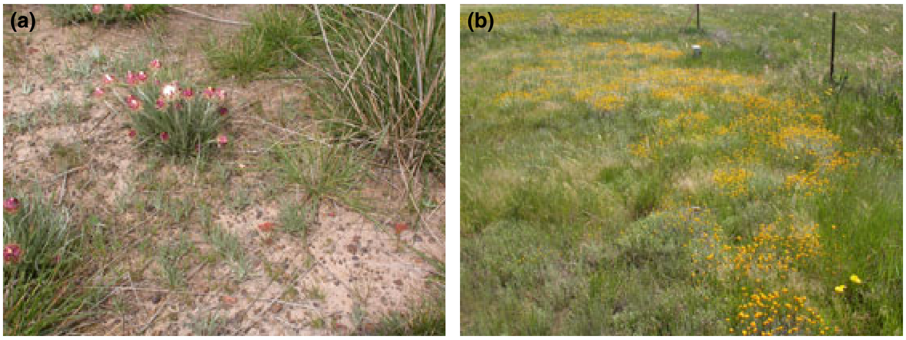

Figure 7. (a & b) a – Hoary Sunray (*Leucochrysum albicans* ssp. *albicans* var. *tricolour*) seedlings mass around a parent plant. b – Common everlasting seedlings (*Chrysocephalum apiculatum*) expanding from original 2 m^2 plots to cover walkways.

Management of the Reconstructed Communities

The GGRP grasslands sown from 2005 to 2007 are now between 3 and 5 years old and support vegetation of varying complexity and quality. Following the seeding phase of the project, a longer-term management component has been undertaken. Each site is managed with a view to developing and preserving the diversity of the original sowing and restricting weeds. Several sites have been mown (some followed by slash removal), others burnt and some remain undisturbed according to the needs of the site and the resources available.

Given favourable conditions plant biomass typically increases over time, and management of native grasses was required, even on some scalped areas. The need to manage biomass was greatest in non-scalped plots where nutrient levels remain elevated from past cropping or grazing (the main problem being the dominance of both exotic and native grasses) (Table 1). Slashing was most useful when cut material could be removed (by baling). Otherwise, litter remained on the cut vegetation and soil surface covering interstitial gaps and suppressing plants. Litter can also return nutrients to soils. It was found that autumn burns were the most useful tool for maintaining diversity. For example, burning in autumn meant that seeding of most native species was not impacted, while biomass and litter were reduced, providing niches for germination. Leaving sites undisturbed was only effective in the more arid areas where biomass remained low. At two sites near to or adjoining a National Park, despite customized fencing, kangaroo grazing severely impacted on forb diversity.

Figure 8. (a–c) Examples of native animals colonizing Grassy Groundcover Restoration Project sites. a – Nest and eggs of Spur-winged Plover (*Vanellus miles*); b – Plains Froglet (*Crinia parinsignifera*); c – Small Copper Butterfly (*Lucia limbaria*).

General implications for restoration practice

McDonald (2000) notes that 'outright ecological reconstruction' will increasingly be required to re-integrate the large areas of landscape fragmented by agriculture, but cautioned such programmes are not a simple 'technological fix'. Both observations seem relevant to the GGRP experience, which sought to demonstrate the feasibility of community reconstruction in highly fragmented agricultural settings. While early outcomes of the GGRP programme have been very encouraging, our experience has been less a straightforward technological fix and more a nuanced integration of many ideas and approaches, most of which have been commonly discussed in the restoration industry. These include (but are not restricted to) the need for proper planning and goal setting, the need to re-establish complex and functional communities, the application of ecological as well as horticultural and agricultural principles, the use of experimentation and monitoring to quantify and inform outcomes, the application of seed production techniques, the use of appropriate weed control methods, the use of specialized restoration technology, and thorough engagement with dedicated landholders and volunteers.

Perhaps a major achievement of this project, therefore, has been the packaging of such ideas into a single programme to bring about significant on-ground outcomes for threatened herbaceous communities at scale; a restoration issue of great importance in south-eastern Australia. Additional, specific lessons we believe can be drawn from the programme, however, are highlighted as follows.

1. Seed production was critical to the success of the seeding programme. This finding may have implications for future restoration planning. Governments and their agencies now have clear evidence of the high value of seed production, which should encourage them to properly support the establishment of regional SPAs to increase the capacity for grassy ecosystem restoration. With appropriate quantities of seed available, the success of the GGRP seeder represents an advance in grassland restoration technology in Australia, allowing the delivery of diverse seed mixtures onto cultivated seedbeds as part of restoration programmes.

2. The reduction in nutrients and weed propagules before sowing appeared critical to the achievement of characteristics (such as high levels of species and functional diversity and low weed abundance) associated with the project's reference communities. While the persistence of these characteristics over the longer term (e.g. 15 years +) still needs to be evaluated, restorationists and agencies should recognize that scalping can provide a key to rapidly re-establishing complex and persistent communities on very weedy sites and can lower the cost of on-going management. Variations on this larger-scale scalping approach could be applied in other situations, such as in larger areas of low-quality grassland (road reserves or farmland) where small scalps could be inserted into grass matrixes (or into weedy areas) and seeded with complex seed mixtures to increase local diversity. Their gradual colonization into adjoining areas could be encouraged through sympathetic management, such as periodic burning.

3. This restoration process has also challenged the commonly held assumption that long-term tenure and management security (e.g. to 50 years) are most likely to occur on public rather than private land. Most private farms hosting GGRP sites, however, had been run by families for generations, and most intended to remain. Their level of commitment and diligence to manage and preserve sites were clear and amplified by their obvious connection to their land. Conversely, while the intent and goals of various managers and others associated

with the public lands that hosted GGRP sites were laudable, the reality of budgetary constraints on public authorities, relatively high staff turnover and competing priorities, reduced our confidence in the long-term management of those sites. In future, commercial 'offsets' may well fund on-farm grassland restoration, with farmers receiving an ongoing income to manage assets, with a potential benefit being drought-resistant pastures for landholders during times when introduced pasture is affected.

Current and future directions

Since 2005, further GGRP projects have reconstructed 30 ha of complex grassland across Victoria, drawing on lessons from the original 13 sites. High-quality complex native grassland (including nationally listed species) has been re-established on several small areas of road reserve in western Victoria. Also, low complexity native grass swards have been sown onto larger areas of roadside. This technique may be an option to reduce the fire risk currently posed by high biomass introduced grasses on rural roadsides. Grassland species have been successfully seeded at a large vineyard to reduce management inputs, lower weed loads, increase pollinator visitation, improve amenity and enhance native biodiversity. The most ambitious GGRP project to date has been undertaken at one site outside Geelong in south-western Victoria with a long-term programme to reconstruct 150 ha of grassy red gum woodland over 10–15 years.

It is hoped that the techniques and knowledge developed through the original GGRP project and those projects that follow on from it will continue to have implications for the broader restoration industry, leading to an increased focus on – and most importantly, support for – the reconstruction of species-rich herbaceous communities in areas where these communities once dominated.

Acknowledgements

Because of the cross-disciplinary approaches required, the GGRP involves many people including landholders, researchers, restorationists, government agencies and volunteers. While bureaucratic and scientific underpinnings were important, it was through the summed energy, enthusiasm and experience of our landholders, land managers, collectors, propagators, contractors, volunteers and staff that our goals were largely achieved. For this, to all involved in the GGRP, we extend our sincere and heartfelt gratitude. For the first 3 years (2004–2007), the project was funded by the NHT and sponsored by the Corangamite, Glenelg-Hopkins and Wimmera Catchment Management Authorities. Subsequent programmes have been undertaken with the support of organizations, such as, Alcoa Australia, the Ararat Shire, VicRoads (western region), Werribee Open Range Zoo, and The Victorian Department of Sustainability's Vision for Werribee Plains programme, and the Corangamite and Glenelg-Hopkins CMAs Victorian Volcanic Plains Project.

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Supporting Information

Additional supporting information may be found in the online version of this article.

Appendix S1. Native genera (and number of species sown and those recorded to date) at GGRP locations as a result of one or more annual sowings from 2005, 2006 and 2007.

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Summary **The Grassy Groundcover Restoration Project (GGRP) has sown thirteen 1 ha plots of species-rich grassland or herbaceous understorey in previously weedy agricultural paddocks in a range of rural locations across southern and western Victoria, Australia. The sown plots are intended as both experimental trials and 'core' areas for the restoration of herbaceous communities native to these regions. Approximately 200 species were grown in Seed Production Areas (SPAs) and successfully sown in the field. Species were most successfully established on areas that were scalped prior to seeding, and least successful on plots that were pre-treated with 1, 2 or 3 years of traditional herbicide weed control. Weed presence was lowest in scalped plots and highest in non-scalped plots. Long-term monitoring will be required to understand the development trajectories and degree of persistence of the sown communities, but in the shorter term (3–6 years of post-seeding) an average of 80% of sown species have established and remain as adult populations. Surveys indicate that in scalped plots (n = 130) vegetation composition, structure and quality has been maintained. Conversely, composition, structure and quality have declined markedly in non-scalped plots (n = 130). Formal surveys and field observations have also revealed that all sites provide a range of habitats which have been colonized by fauna from a variety of trophic levels. The implications of building on these trials to realize complex grassy ecosystem restoration at larger scales are discussed including the securing of sufficient quantities of high-quality seed, the use of mechanized broad-scale direct-seeding techniques and the effectiveness of using complex mixtures of species early in the restoration cycle.**

Key words: *direct-seeding, grassland, nutrients, restoration, weed control.*

