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Using ecological attributes as criteria for the selection of plant species under three restoration scenarios

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Abstract We used a conjoint analysis to reveal the preferences of experts with respect to plant attributes under three different restoration scenarios (high-level conservation, functional native vegetation, perennial native pasture) and to generate prioritized lists for restoration of grassy woodland species. Nineteen experts participated in the conjoint analysis. The sample comprised researchers and practitioners with local knowledge of grassy ecosystems. The survey involved repeated pairwise ranking of the relevance of attributes of seven ecological criteria. The relative weightings of the attributes were then used to generate the 50 top-ranked species for each of the three scenarios. Overall phosphorus tolerance was considered the most important criterion, followed by grazing tolerance. Species favoured for high-level conservation management included nutrient- and grazing-intolerant plants with narrower distributions and some species of threatened status. The two scenarios with histories of fertilization and varying levels of ongoing grazing were most similar in that their lists were dominated by graminoids and did not contain any shrubs or geophytes. The ranking of species provides an initial list that could be tailored to take into account specific site conditions and additional knowledge of species. This approach to the selection of species shows promise as either a repeatable process to select species for particular sites, or to generate a classification of species that could be used generically for a small number of common situations.

Key words: 1000Minds, conjoint-analysis, grassland, grassy woodland, plant functional trait.

INTRODUCTION

The translocation of plants is a conservation tool to assist dispersal across modified landscapes or to anticipate climate change, by relocating species within and slightly beyond their current range (Seddon 2010). Threatened species, typically with small populations and reduced ranges, are the most discussed candidates for translocation, as they are perceived to be limited by their capacity to disperse through fragmented landscapes. However, the establishment and persistence of these most needy species is prone to failure (Pywell *et al*. 2003; Rout *et al*. 2007) because they are likely to be species with insufficient seed availability (Kirmer *et al*. 2008), a compromised genetic base (Frankham 2004) and with highly specific (or unknown) habitat requirements. Nonetheless, methods need to be developed for the establishment of even 'poor performing' species if we are going to minimize species losses in the future (Pywell *et al*. 2003; McIntyre 2011). While much discussion in the literature is devoted to the care and risks of plant translocations, in practice, translocations of a range of non-threatened species is undertaken on a very large scale, for example 29 million native seedlings were planted in Australia 2000–2001 (Environment Australia 2002). While attempts are made to match the material planted to the local vegetation, precision and accuracy are still generally lacking in the selection of populations and species (e.g. see Mortlock 2000).

The success of a translocation is related to the biological attributes of the species, but only in the context of conditions at the recipient site (Pywell *et al*. 2003). Few species are adapted to all site conditions, or if they were, they would most likely be considered weedy, and not in need of translocation. For example, land use history has been recognized as a constraint for the restoration of grassy woodland vegetation (Prober *et al*. 2005; McIntyre & Lavorel 2007; McIntyre 2008). Depending on the intensity of previous agricultural use (fertilization, native species depletion, grazing pressure, etc.), receiving sites may provide serious obstacles to the return of self-sustaining populations because processes necessary for regeneration or growth may be disrupted (Prober *et al*. 2002; Wilkins *et al*. 2003; Dorrough *et al*. 2006; Fischer *et al*. 2009; Gilbert *et al*. 2009). Successful selection from amongst plant species candidates will require matching species habitat requirements to identified receiving sites. Currently, this tends to be done on an *ad hoc* basis, with seed availability being a major constraint (Mortlock 2000) and with little regard to receiving site suitability.

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While experimental work has shown plants traits to be important predictors of establishment success at a site (Sandel *et al.* 2011; Martínez-Garza *et al.* 2013), few have translated these relationships into species or generic lists of species for planting at different types of site. Also, there is an understandable tendency to report on traits related to early establishment success (e.g. Clark *et al.* 2012; Haan *et al.* 2012; Kulpa & Leger 2013) rather than matching species to habitat using traits relating to establishment and long-term persistence (e.g. Burt 2012). Despite the large number of active restoration programs, relatively little is known about the weightings that managers consciously, or subconsciously, give to specific traits when selecting plant sources to restore degraded sites. This is particularly the case for herbaceous vegetation where there is a wide potential choice of species, but a very limited number actually used. In anticipation of future expansion of the use of ground layer species in restoration projects, we ask how might species be selected to best achieve successful establishment and persistence at receiving sites?

In this paper we describe a methodology for selecting plant species for restoration which harnesses expert opinion on the relative importance of ecological criteria (including some traits). The process involved the following steps:

1. Identification of a *plant assemblage* for which restoration is considered important – in this case we identified 250 ground layer plants of grassy woodland, with distributions that included the New South Wales Southern Tablelands.
2. Creation of three *restoration scenarios*, characterized by land use histories and management aims that are typical of temperate grassy woodlands.
3. Selection of *ecological attributes* that might have relevance in determining the establishment and persistence of a species at the range of receiving sites. The 250 species were coded for the attributes of each of the seven criteria selected.
4. Use of a *conjoint analysis survey* to consult experts and formulate overall weightings of the attributes under the different restoration scenarios. We used the weightings to identify the top 50 species for use in each restoration scenario.

We interpret the resulting lists for the three habitats and analyse how the attributes selected vary amongst experts and between restoration scenarios. Finally, we discuss the utility of the methodology.

METHODS

Plant assemblage

We merged three unpublished species lists describing the flora of temperate eucalypt grassy woodlands and culled them to remove the following: uncertain identifications, high altitude species, trees, shrubs > 1 m high, ferns, species from sclerophyll communities, wetland and riparian species, species not found on the NSW Southern Tablelands and exotic species. This distilled down to a list of 250 taxa.

Restoration scenarios

Three restoration scenarios have been characterized taking into account the history, current condition, objectives of the restoration and future management of hypothetical receiving sites. These three scenarios are considered to cover most general situations, and to account for the land use history of much of the temperate grassy woodland biome in southeastern Australia as described in McIntyre and Lavorel (2007), McIntyre (2011).

Scenario 1 – High-level conservation

Site history. Commercial grazing property with a history of heavy grazing and light fertilization. Property now managed for conservation with no livestock grazing in the previous decade.

Current condition of vegetation. Available phosphorus levels have declined to levels comparable to never-fertilized soil ('native' levels), but many grazing- and nutrient-sensitive species are likely to be absent or reduced to a few individuals. Native diversity is still moderately high and the native grass matrix is dominant over most of the landscape. Annual weeds occur throughout, sometimes at low levels while some areas, notably sheep camps and productive areas, are dominated by annual and/or perennial weeds.

Objectives for restoration. The light fertilizer history would have maintained native diversity sufficiently to make the land attractive for conservation management, but the depletion of some species would indicate the need for some restoration The aim is to maximize the condition and diversity of the ground layer for conservation purposes, and to either re-introduce or boost the populations of grazing- and nutrient-sensitive species.

Management considerations. Intent is to manage grazing pressure at a very low level and use fire to control biomass as required, thus restoring an endogenous disturbance regime (Gammage 2011). Intensive management of translocation process is anticipated, including weed control as necessary. Direct seeding techniques (seed availability permitting) with minimal disturbance would be preferred, in order to reduce weed invasion into native-dominated swards.

Scenario 2 – Restoration of functional vegetation

Site history. Commercial grazing paddock with pasture improvement history involving periodic cultivation and

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sowing of exotic grasses and legumes, and fertilization every few years. These inputs ceased 5–10 years ago but sheep grazing has continued to the present time.

Current condition of vegetation. Native tussock grassland matrix has been replaced by annual and some perennial exotic species. Fewer than 15 fertility- and grazing-tolerant native species have persisted. Some mature eucalypts persist but no regeneration of trees is evident. Available phosphorus levels are elevated, but below levels recommended for optimum pasture production (Colwell 30 mg kg^{-1}, Clements *et al.* 2000). High nitrogen levels are associated with sheep camps. Some ongoing soil erosion.

Objectives for restoration. To achieve increase native plant diversity while maintaining some livestock production with no further soil losses. To restore dominance of native grasses and some of the original native forb diversity. To create a low-fertility environment suitable for tree regeneration by ceasing fertilizer inputs. Perennial grass dominance (native or exotic) and eucalypt regeneration would restore soil functions (e.g. protection from erosion, stability of production, nutrient recycling and rainfall infiltration).

Management considerations. Both direct seeding and tubestock planting could be undertaken. Removal of livestock possible for as long as required to establish new species. Subsequent grazing would be strategic to take into account plant phenology of sensitive species rather than maximize production. Few resources for weed control available and herbicide spraying should be minimal. No more fertilization planned.

Scenario 3 – Perennial native pasture

Site history. Commercial grazing paddock with pasture improvement history involving periodic cultivation and sowing of exotic grasses and legumes, and regular fertilization. More recently, fertilization has been sporadic as seasons and prices have dictated.

Current condition of vegetation. Dominated by annual exotic grasses and forbs. There are a few fertility- and grazing-tolerant native species but they do not dominate. There are no trees. Available phosphorus levels are high, near levels recommended for optimum pasture production (Colwell 30 mg kg^{-1}, Clements *et al.* 2000). Seasonally high nitrogen levels are associated with sheep camps. Some ongoing soil erosion.

Objectives for restoration. To restore pasture to native perennial dominance with a small number of native forbs. To obtain moderate livestock production with good cover and no further soil losses.

Management considerations. The site would need to be direct-seeded to achieve large-scale restoration. There would be ongoing fertilization and grazing, but reduced as necessary for native perennial grass establishment and persistence. Livestock production would take priority over native forb persistence, though the latter is desirable.

Selection of ecological criteria

Considering the above scenarios, the following seven ecological criteria (and their attributes, in italics) were selected as being relevant to the establishment and persistence of species. The rationale is given for each choice.

Strictly speaking, three of the criteria are biological traits (dispersal, life-cycle, seed availability) two relate to distribution patterns (geographical range, conservation status) and two are ecological responses (phosphorus and grazing tolerance).

Conservation status

Formally listed as threatened at state or national level:

- Not threatened
- Threatened

We are using formal listing (threatened/rare/endangered) as an indication of some level of actual or imminent depletion of populations. At sites where establishment and persistence is unlikely to be successful, or where there is no ongoing management for conservation, we would expect threatened species not to be selected for restoration.

Dispersal

Probability of long-distance dispersal indicated by morphology:

- Low (no evident structures)
- Medium (ingestion, adhesion)
- High (wind, very small seeds)

Well-dispersed seeds are more likely to arrive at a suitable site for establishment over distances than seeds with low dispersal properties. The former may therefore be less disrupted by habitat fragmentation and their need for re-introduction is likely to be lower. Conversely, poorly dispersed seeds are less likely to be able to re-colonize sites without assistance.

Geographical range

Latitudinal range sourced from collection records:

- Intermediate (<1000 km)
- Wide (1000–2000 km)
- Very wide (>2000 km)

Species with restricted distributions may have more limited genetic variability, have more limited seed sources, and greater vulnerability to extinction in the face of environmental change and thus be more likely candidates for

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assistance. Note that the range classes are relatively wide, reflecting typical distributions for these grassland species (McIntyre 1992).

Seed availability

Integrated assessment of fecundity, quality and ability to collect:

- Low
- Medium
- High

The amount of propagating material available will affect the cost of sourcing material, and the area that can be planted out, and may have a bearing on method of establishment. On the face of it, more abundant seed producers are a better choice, but poor seeders may be declining for this reason, and may be more favoured where conservation and high diversity are a priority.

Life-cycle

- Annual
- Perennial

This is a perennial-dominated vegetation type; most species are perennial, and perennial grasses provide stability and functionality in the vegetation. Annuals are associated with rapid growth and may be favoured where rapid covering of the ground is desired. Their requirement for some ongoing disturbance will make them a particularly useful component at sites that are regularly grazed or burnt. Annuals are probably only suitable for establishment by direct seeding. Annuals included species that readily establish and reproduce within one year, even if they persist for longer.

Phosphorus tolerance

Persistence at sites with elevated available P levels:

- Very low
- Low
- Moderate

Most species in this ecosystem are adapted to low available P and cannot compete with exotics where levels are elevated. Species rated 'very low' are likely to have been depleted in the landscape due to agricultural use and are therefore of more conservation concern. Species with higher persistence may be necessary for successful persistence where higher P levels are ongoing at a site.

Grazing tolerance

Persistence at sites with commercial levels of livestock grazing:

- Very low
- Low
- Moderate-high

This attribute relates to the likelihood of this species being of conservation concern due to the historical and current dominance of grazing in the landscape. Intolerant species may need re-introduction at sites with a grazing history for which very light grazing is now planned. Some tolerant species will require ongoing grazing to persist at a site.

Conjoint analysis survey

Nineteen people (including the two authors) participated in the online surveys. These were ecologists (10) and practitioners (9) with regional knowledge of grassy woodlands. The three scenarios were addressed through three different surveys. Seventeen participants completed all three surveys (one addressed Scenario 1 only, and one addressed 2 and 3). We used conjoint-analysis to reveal the preferences concerning the relative importance of the seven pre-selected plant attributes, and to generate prioritized lists for restoration of grassy woodland species for each of the three scenarios.

Conjoint-analysis (also known as Choice modelling or Discrete Choice experiments) is a statistical technique to determine how people value (or weight) different features that make up an outcome of interest. It has been recommended as the best approach, theoretically and practically, for valuing health-care benefits (Krantz 1972; Golan *et al.* 2011), but it is increasingly been used in other areas such as corporate strategic management, monetary-policy (Smith 2009), and agronomy (Smith & Fennessy 2011). In our study, the participants were asked to consider the options where the primary question was as follows: Which of these attributes would you select when choosing species for restoration under Scenario x? We used an Internet-based software package known as '1000Minds' (http://www.1000minds.com) to support the process. The software implements a method for deriving weights, known by the acronym PAPRIKA (Potentially All Pairwise Rankings of all possible Alternatives). The method involves respondents being asked (via the online software) to choose the attributes best suited to the restoration scenario by means of a series of binary selections (pairs of 'hypothetical species'). Each hypothetical species is presented a pair of criteria/attribute combinations. These simple pairwise-ranking questions are repeated with different pairs of hypothetical alternatives, all involving different combinations of the criteria and their attributes, until enough information about preferences has been collected to accurately rank the criteria and their attributes (Hansen & Ombler 2008). The number of questions asked is minimized because each time one is answered the method eliminates all other possible questions that are implicitly answered as corollaries of those already answered. This reduces the workload on participants.

Two of the steps to create a decision model for conjoint analysis in 1000Minds involve: (i) an *a priori* ranking of the levels of each criterion to allow the software to make the questions in the survey, and (ii) to enter the alternatives (i.e. real species), to further reveal how participant's preference values after the survey could generate prioritized lists for restoration of grassy woodland species (for more details see *User guide for 1000Minds*, http://www.1000minds.com/about/guides/guide-preferences-survey). Thus, to set up the model

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(prior to the survey), we used the seven ecological criteria listed above and the attributes of each criterion were ranked *a priori* for each scenario. For example, for Scenario 1 – *High-level conservation*, the attribute '*Threatened*' was higher ranked than '*Not-threatened*' conservation status, whereas for Scenario 3, the same attributes were ranked in the reverse order. Inherent to the model, is that the initial relative importance attached to a criterion depends on the range of levels specified for it (and for the other criteria too) (Hansen & Ombler 2008). In the setup model, we balanced the weight of the criteria assigning three levels for each criterion when possible (see section *Selection of ecological criteria)*. Two of the seven criteria, 'Conservation status' and 'Life-cycle', had two attribute levels. Therefore, in the set-up these were ranked in second place, whereas the other five were equally ranked first.

We also entered the descriptions of the real species (the alternatives). Each of the 250 plants in the identified assemblage was coded, identifying one attribute for each of the seven criteria. Coding for each species is provided in the supporting information (Appendix S1). The sources of species information on attributes are listed below.

Conservation status: Government legislation.

Dispersal: Seed dispersal morphology defined as in McIntyre *et al.* (1995); species information sourced from Harden (1990–1993) and McIntyre *et al.* (1995).

Geographical range: http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm (accessed October–November 2010).

Seed availability: Assessed by N. Taws and B. Vanzella (Greening Australia).

Life-cycle: Harden (1990–1993) and field observation (S. McIntyre).

Phosphorus tolerance: unpublished species-level data underpinning Dorrough and Scroggie (2008) and where no specific data, the functional groups of Dorrough and Scroggie (2008) were used in conjunction with field observations (S. McIntyre).

Grazing tolerance: Dorrough and Scroggie (2008) and the species-level data underpinning this publication; Díaz *et al.* (2007); McIntyre *et al.* (2002); McIntyre and Lavorel (2001), field observations (S. McIntyre).

From participants' answers, preference values representing the relative importance (or 'weights') of the criteria were obtained via mathematical methods based on linear programming (explained in detail in Hansen & Ombler 2008). We compared their values within scenarios. 1000Minds then ranked the 250 species of the plant assemblage from first to last according to their 'total scores'. Each species under consideration is 'scored' according to its performance on the criteria, and then the corresponding point values across the criteria are summed to get the species' 'total score' (for more detail of the method see *PAPRIKA*, http://en.wikipedia.org/wiki/Potentially_all_pairwise_rankings_of_all_possible_alternatives; Hansen & Ombler 2008). We selected the 50 top ranked species that were collectively recommended for each scenario and we calculated the percentage of those species that share similar traits within each criterion per each scenario. We also conducted two-way ANOVAs, to compare how practitioners and researchers differed in the relative weight given to each attribute across the three scenarios. Data were arcsin transformed to meet assumptions of ANOVA.

RESULTS

Relative weighting of criteria

Overall phosphorus tolerance was considered to be the most important criterion for use in the selection of species (Table 1) and this was weighted more highly than the other six criteria, with the exception of grazing tolerance which was considered equally as important as phosphorus tolerance, but only in the native perennial pasture situation (Scenario 3). Geographical range only had importance in the high level conservation scenario, for which species of narrower latitudinal range were preferred (Table 2). Conservation status was similarly weighted across scenarios (Table 1), though the choice of attributes was different with threatened species being chosen for the high level conservation scenario, but not for the others (Table 2). Seed availability was only considered important for Scenarios 2 and 3.

Scenario 1 – High-level conservation

Participants prioritized phosphorus and grazing intolerance under this scenario. Of the 50 top-ranked species 42 had very low grazing tolerance combined with low, or very low, tolerance of phosphorus (Tables 1,2). Shrubs and geophytes were well represented in this group, but no annual species were highly ranked (Fig. 1). Participants also rated low availability of seed as being less important for this scenario (Table 1). The 50 top-ranked species in the high conservation scenario were entirely different from those selected in Scenarios 2 and 3 both in species composition (Table 3) and life-form (Fig. 1).

Scenarios 2 and 3 – Restoration of functional vegetation and perennial native pasture

These two scenarios produced species rankings of far greater similarity and had 35 top-ranked species in common and no species in common with Scenario 1 (Table 3). This result appears to reflect the fact that the sites would have elevated nutrients, some ongoing grazing and would require more broad-scale plant establishment than the high-level conservation scenario. The ranked species list generated for Scenarios 2 and 3 included no species with very low phosphorus or low grazing tolerance, and proportionally more moderately tolerant species, with greatest emphasis on grazing tolerance under Scenario 3 (Table 2). High seed availability was considered important under both scenarios, most likely in anticipation of the need to transform the ground cover over large areas, in contrast to supplementing or establishing populations in native-dominated vegetation

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Table 1. Ranking of importance of the seven ecological criteria subjected to conjoint analysis involving 19 participating researchers and restoration practitioners, considering each of three restoration scenarios

Criterion/attributes	Scenario 1: High level conservation	Scenario 2: Functional vegetation	Scenario 3: Native pasture
Conservation status	4th	6th	5th
Not threatened	0 (0)	10 (8.3)	9.7 (8.3)
Threatened	14.1 (8.3)	0 (0)	0 (0)
Dispersal	5th	5th	6th
Low	13.9 (17)	11 (17)	0 (0)
Medium	6.8 (8.3)	5.0 (8.3)	3.4 (8.3)
High	0 (0)	0 (0)	6.9 (17)
Geographical range	**3rd**	7th	7th
Intermediate (<1000 km)	**16** (17)	7.7 (17)	0 (0)
Wide (1000–2000 km)	7.7 (8.3)	4.1 (8.3)	2.5 (8.3)
Very wide (>2000 km)	0 (0)	0 (0)	5.3 (17)
Seed availability	7th	**3rd**	**3rd**
Low	6.7 (17)	0 (0)	0 (0)
Medium	3.5 (8.3)	8.2 (8.3)	6.9 (8.3)
High	0 (0)	**14** (17)	**13** (17)
Life-cycle	6th	4th	4th
Annual	0 (0)	0 (0)	0 (0)
Perennial	11 (8.3)	12 (8.3)	13 (8.3)
Phosphorous tolerance	**1st**	**1st**	**2nd**
Very low	**23** (17)	0 (0)	0 (0)
Low	19 (8.3)	13 (8.3)	11 (8.3)
Moderate	0 (0)	**26** (17)	**24** (17)
Grazing tolerance	**2nd**	**2nd**	**1st**
Very low	**16** (17)	0 (0)	0 (0)
Low	8.7 (8.3)	10 (8.3)	11 (8.3)
Moderate-high	0 (0)	**18** (17)	**28** (17)

Each attribute's relative importance (mean %) is given, with the value of the highest-ranked attribute (i.e. the highest mean % value) for each criterion representing that criterion's importance relative to the other criteria. The original set-up ranked attributes for each scenario (for details see section *Conjoint analysis survey*) are given in brackets. Top three criteria/attributes for each scenario are indicated by values in bold.

in Scenario 1. Participants did not signal a strong preference for any particular geographical range under Scenarios 2 and 3, but they did include annual plants (Table 1) (Table 2), and under Scenario 3, high dispersal ability was favoured.

Scenario 2 had 26 graminoids (grasses, sedges, rushes) and 24 forbs in the top ranks while Scenario 3 had more graminoids (32) and fewer forbs (18). The graminoids tend to be more grazing tolerant (Dorrough & Scroggie 2008) and were all rated as low-high in their grazing tolerance – none were rated very low (Appendix S1). Moreover, all the top-ranked graminoids in Scenario 2 and 3 were classified as moderate-highly grazing tolerant. There were 15 ranked species that were unique to each of the Scenario 2 and 3 lists (Table 3). In Scenario 2, only two of these unique species were grasses, the rest were dicots. Eight of the unique species in Scenario 3 were grasses. Amongst the 'unique' dicots, there more species with low levels of grazing tolerance in the Scenario 2 list. This is consistent with the more modest conservation aims of Scenario 3, and the lesser emphasis on livestock grazing in Scenario 2.

Differences between practitioners and researchers in weightings

We compared how the participant groups (researchers and practitioners) differed in their weighting of the seven traits across scenarios. There were no significant differences between scenarios or groups for Phosphorus tolerance, Conservation status or Life cycle. Significant differences were found between scenarios, but not groups for Geographical range, Dispersal and Seed availability (Fig. 2b–d). There was a significant Scenario x Participant interaction for Grazing tolerance (Fig. 2a). Researchers weighted this trait more strongly under Scenario 1 (i.e. they considered species with low tolerance to grazing as more suitable for this scenario) than under Scenario 2, whereas practitioners did the contrary. Both participant groups weighted this trait similarly under Scenario 3. There was greatest agreement between participant groups for Scenarios 2 and 3. In Scenario 2, 44 of the 50 species were selected by both groups, while 49 were shared in Scenario 3. Greater divergence in choice was evident in Scenario 1, with only 30 shared species top-ranked (data not shown).

Table 2. Distribution of attributes of seven ecological criteria across the initial list of 250 potential species choices and the top 50 ranked species for each of the three scenarios using conjoint analysis

Criterion/attributes	Total no. spp. with attribute	Scenario 1: High level conservation No. of top 50 ranked species with attribute (% of total)	Scenario 2: Functional vegetation No. of top 50 ranked species with attribute (% of total)	Scenario 3: Native pasture No. of top 50 ranked species with attribute (% of total)
Conservation status				
Not threatened	241	41 (17)	50 (21)	50 (21)
Threatened	9	**9 (100)**	0	0
Dispersal				
Low	134	41 (31)	24 (18)	10 (7)
Medium	50	3 (6)	18 (36)	20 (40)
High	66	6 (9)	8 (12)	20 (30)
Geographical range				
Intermediate (<1000 km)	28	13 (46)	6 (21)	4 (14)
Wide (1000–2000 km)	133	32 (24)	32 (24)	26 (20)
Very wide (>2000 km)	89	5 (6)	12 (13)	20 (22)
Seed availability				
Low	72	27 (38)	4 (6)	1 (1)
Medium	36	4 (11)	8 (22)	9 (25)
High	55	1 (2)	**32 (58)**	**36 (65)**
Life-cycle				
Annual	31	0	3 (10)	6 (19)
Perennial	219	49 (23)	47 (22)	44 (20)
Phosphorus tolerance				
Very low	42	**21 (50)**	0	0
Low	137	27 (20)	12 (9)	14 (10)
Moderate	71	2 (3)	**38 (54)**	**36 (51)**
Grazing tolerance				
Very low	74	**42 (57)**	0	0
Low	82	8 (10)	6 (7)	1 (1)
Moderate-high	93	0	44 (47)	**49 (53)**

Attributes with 50% or greater representation in a priority list are indicated by values in bold.

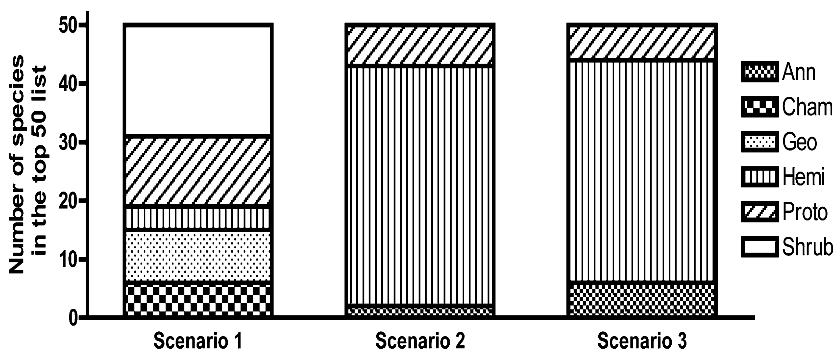

Fig. 1. Number of species across major life-forms (modified from Raunkiaer (1934) that were top 50 ranked in three restoration scenarios. Annual (Ann), chamaephyte (Cham), geophyte (Geo), hemicryptophyte (Hemi), protohemicryptophyte (Proto), shrub (Shrub)).

DISCUSSION

The selection process was achieved though the weighting of attributes only, with no consideration of species identity and thus presents a method of ranking a plant species by appropriately skilled people, but without a requirement for them to have detailed knowledge of hundreds of species. As suggested by Clark *et al.* (2012) traits are a useful common language in restoration science. Our review of the lists suggests that the results are intuitively sensible, and reflect the kind of vegetation that would

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Table 3. Ranking of the top 50 species per scenario resulting from the average weighting of attributes by all 19 participants in the conjoint analysis

Scenario 1: High level conservation	Rank	Scenario 2: Functional vegetation	Rank	Scenario 3: Native pasture	Rank
**Swainsona recta*	1st=	*Rytidosperma auriculatum*	1st=	*Panicum effusum*	1st
**Swainsona sericea*	1st=	*Rytidosperma carphoides*	1st=	*Juncus australis*	2nd=
**Dichopogon fimbriatus*	3rd=	*Austrostipa bigeniculata*	1st=	*Juncus filicaulis*	2nd=
**Dichopogon strictum*	3rd=	*Microlaena stipoides*	4th=	*Juncus subsecundus*	2nd=
**Gompholobium huegelii*	3rd=	*Oxalis perennans*	4th=	*Senecio hispidulus*	2nd=
**Lepidium hyssopifolium*	6th	*Rytidosperma caespitosum*	6th=	*Austrostipa rudis*	6th=
**Acacia gunnii*	7th=	*Rytidosperma monticola*	6th=	*Rumex brownii*	6th=
**Pultenaea subspicata*	7th=	*Rytidosperma racemosum*	6th=	*Rytidosperma caespitosum*	8th=
**Ammobium craspedioides*	9th=	*Rytidosperma setaceum*	6th=	*Rytidosperma monticola*	8th=
**Dodonaea procumbens*	9th=	*Austrostipa densiflora*	6th=	*Rytidosperma racemosum*	8th=
**Rutidosis leptorhynchoides*	9th=	*Austrostipa scabra*	6th=	*Rytidosperma setaceum*	8th=
**Dillwynia cinerascens*	12th=	*Bothriochloa macra*	6th=	*Austrostipa densiflora*	8th=
**Grevillea lanigera*	12th=	*Convolvulus angustissimus*	13th	*Austrostipa scabra*	8th=
**Grevillea ramosissima*	12th=	*Austrostipa rudis*	14th=	*Bothriochloa macra*	8th=
**Swainsona monticola*	12th=	*Rumex brownii*	14th=	*Microlaena stipoides*	15th=
**Thesium australe*	16th	*Sporobolus creber*	16th=	*Oxalis perennans*	15th=
**Cryptandra amara*	17th=	*Wahlenbergia communis*	16th=	*Rytidosperma auriculatum*	17th=
**Pimelea curviflora*	17th=	**Cymbonotus preissianus*	18th	*Rytidosperma carphoides*	17th=
**Pimelea glauca*	17th=	*Juncus australis*	19th=	*Austrostipa bigeniculata*	17th=
**Thysanotus patersonii*	17th=	*Juncus filicaulis*	19th=	*Euchiton japonicus*	20th=
**Scleranthus diander*	21st	*Juncus subsecundus*	19th=	*Wahlenbergia luteola*	20th=
**Bossiaea buxifolia*	22nd=	*Senecio hispidulus*	19th=	**Dysphania pumilio*	22nd=
**Cullen microcephalum*	22nd=	**Urtica incisa*	23rd	**Lachnagrostis filiformis*	22nd=
**Dillwynia sericea*	22nd=	**Plantago gaudichaudii*	24th=	**Chrysocephalum apiculatum*	24th=
**Goodenia pinnatifida*	22nd=	**Plantago varia*	24th=	**Pennisetum alopecuroides*	24th=
**Helichrysum ruditolepis*	22nd=	**Poa sieberiana*	24th=	*Sporobolus creber*	24th=
**Indigofera adesmiifolia*	22nd=	**Cymbonotus lawsonianus*	27th	*Wahlenbergia communis*	24th=
**Swainsona behriana*	22nd=	*Rytidosperma duttonianum*	28th	**Crassula sieberiana*	28th=
**Lepidium ginninderrense*	29th	*Panicum effusum*	29th	**Lachnagrostis aemula*	28th=
**Thelymitra carnea*	30th	*Portulaca oleracea*	30th	**Chloris truncata*	30th=
**Acrotriche serrulata*	31st=	*Euchiton japonicus*	31st=	*Convolvulus angustissimus*	30th=
**Astroloma humifusum*	31st=	*Wahlenbergia luteola*	31st=	**Epilobium billardierianum*	30th=
**Leucopogon virgatus*	31st=	*Poa labillardierei*	33rd	**Aristida ramosa*	33rd=
**Diuris pedunculata*	34th	**Lomandra bracteata*	34th=	**Themeda australis*	33rd=
**Brachyloma daphnoides*	35th=	**Ranunculus sessiliflorus*	34th=	**Euchiton sphaericus*	35th
**Burchardia umbellata*	35th=	*Carex appressa*	36th=	*Aristida behriana*	36th=
**Caesia calliantha*	35th=	*Centella cordifolia*	36th=	*Aristida vagans*	36th=
**Bulbine bulbosa*	38th=	*Chamaesyce drummondii*	36th=	**Rytidosperma erianthum*	36th=
**Hibbertia riparia*	38th=	*Aristida behriana*	39th=	*Rytidosperma laeve*	36th=
**Laxmannia gracilis*	38th=	*Aristida vagans*	39th=	*Rytidosperma pilosum*	36th=
**Linum marginale*	41st	**Rytidosperma erianthum*	39th=	**Enneapogon nigricans*	36th=
**Arthropodium milleflorum*	42nd	*Rytidosperma laeve*	39th=	*Senecio quadridantatus*	42nd
**Polygala japonica*	43rd=	*Rytidosperma pilosum*	39th=	*Portulaca oleracea*	43rd
**Scleranthus biflorus*	43rd=	*Senecio quadridantatus*	44th	*Poa labillardierei*	44th
**Bossiaea prostrata*	45th=	**Solenogyne dominii*	45th=	*Carex appressa*	45th=
**Echinopogon caespitosus*	45th=	**Solenogyne gunnii*	45th=	*Centella cordifolia*	45th=
**Echinopogon cheelii*	45th=	**Geranium retrorsum*	47th=	*Chamaesyce drummondii*	45th=
**Hovea linearis*	45th=	**Hydrocotyle laxiflora*	47th=	*Rytidosperma duttonianum*	48th
**Brachyscome dentata*	49th=	**Mentha satureioides*	47th=	**Euchiton involucratus*	49th=
**Cullen tenax*	49th=	**Stellaria pungens*	47th=	**Wahlenbergia multicaulis*	49th=

Plant names follow: http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm. The asterisk '*' indicates ranked species unique to that scenario.

be expected to be able to establish and persist at the three types of sites. Thus the functional vegetation and pasture scenarios led to the identification of a herbaceous, grass-dominated sward with a range of the more grazing- and nutrient-tolerant grasses (Dorrough *et al.* 2011) and a modest number of similarly tolerant forbs, all relatively common, but which could easily have been previously eliminated

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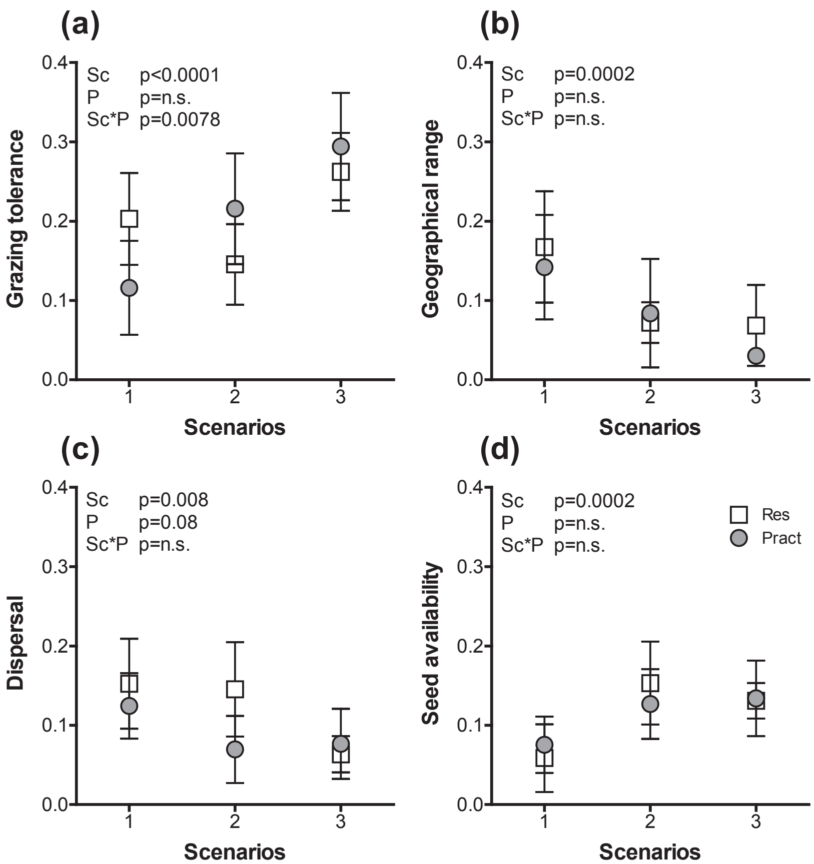

Fig. 2. Relative weights given to traits by the two groups of participants (P) for each of the three scenarios (Sc). Means (±95% CI) are given for researchers (white squares) and practitioners (grey dots) for each scenario. Only significant results are shown (phosphorus tolerance, conservation status and life cycle were not significant).

by cultivation, and very heavy grazing and/or fertilization. Seed availability was only considered important for these scenarios (2 and 3, Table 1), where establishment of very large numbers of plants would be considered important and species with high level of available seed were favoured (Table 2).

Reflecting the most distinctive receiving site, Scenario 1 generated the most distinctive species list, with a diverse array of life-forms (Fig. 1) and many species that would be more demanding to introduce such as orchids, threatened species and species with low seed availability. Shrubs and geophytes were well represented in this group as these life-forms are negatively correlated with high phosphorus and heavy grazing (Dorrough & Scroggie 2008), and participants prioritized phosphorus and grazing intolerance under this scenario (Tables 1 and 2). No annual species were highly ranked in this scenario, which is consistent with an expectation of low ongoing disturbance. It would be expected that the conservation scenario would demand the most challenging species (Pywell *et al.* 2003; Rout *et al.* 2007), and comparison of our three lists with the establishment outcomes for 65 species reported by Gibson-Roy *et al.* (2007), suggests that establishment of the Scenario 1 species is likely to be more difficult.

The lists generated provide only an initial pool of candidate plants from which a final selection needs to be made for a specific site. A proportion of the species list generated for a scenario may already occur at a site, and unless populations were very small and needed augmentation, it might be preferable not to introduce material for species that are already established in numbers. There are also other aspects of suitability that managers would consider that were not covered by the criteria included in the analysis. For example, microhabitat requirements, lithology and aspect would ideally be matched. Unfortunately, our knowledge of these is patchy and they could not readily be coded up as attributes. Nonetheless, it would make sense for a manager to edit the list to remove species that are unlikely to be suitable based on their local field knowledge. Availability of seed sources would also need to be assessed informally in this way. Low availability of seed can be a particular problem for forbs that are limited in population size, and for stress-tolerant species that have

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low reproductive output. Ranking seed output as less important for high-conservation sites is consistent with the greater challenge of establishing stress-tolerant species. Taking all these into account, it is likely that a longer list of the top ranking species (e.g. the top 100) would be most useful to consult in this final selection process.

In the case of the high level conservation, there is more to lose in making poor selections, as threatened species and species of low fecundity are involved. Participants accepted low availability of seed, apparently acknowledging that species with conservation needs may have low fecundity, and extra efforts to obtain seed may be justified. Considerably more care would be needed to select a subset of species that were carefully matched to donor and receiving environments and to take into account genetic and conservation considerations around endangered species (Broadhurst & Young 2007; Broadhurst *et al.* 2008).

We coded additional criteria (family, life form, seed dormancy) but these proved not suitable for the conjoint analysis. Nonetheless, they may be useful in the final selection of species, for example consideration of life-form would be important in determining the structural nature of the vegetation being restored. Managers might also take into account that fertilized sites will have declining phosphorus levels over time, and that additional, less tolerant, species could be included in later stages of the restoration process.

Our approach has focused on the broader matching of the species to the receiving site rather than the short-term considerations of rapid establishment and cover which tends to select for attributes such as clonality (Clark *et al.* 2012), rapid emergence, large plants and large seeds. Attributes associated with rapid establishment do not necessarily match the traits associated with persistence (Kulpa & Leger 2013). This is particularly relevant to the case of vegetation in the high conservation scenario, where slow growth rates are an adaptive attribute in stressed habitats (Grime 1979).

While it would be feasible to develop other approaches that employ consideration of the receiving site and expert ranking of ecological attributes relevant to that site, our method shows promise either as a repeated process whereby the software continues to be used to select species for new sites, or to generate a classification of species relevant to a fixed number of common situations. There was some variation between researcher and practitioner groups in the ranking of attributes, but local experts on this ecosystem are limited in number. We came close to exhausting possibilities for additional participants with local knowledge, although there may be some capacity to further refine the results through a larger sample of experts covering a wider range of biomes.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Coding of 250 plant species into attributes for seven ecological criteria.

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