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Footnote

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Direct seeding in weed infested remnant grassland situations using native forbs

Randall Robinson, Sustainability Group, Victoria University, c/o PO Box 122, Hurstbridge, Victoria 3099, Australia.

Introduction

Approximately two hundred species of forbs that occur within the lowland grassy ecosystems of south-eastern Australia are listed as rare and endangered (Commonwealth of Australia 2000, Ross 2000). Many of these species were formerly widespread and abundant but have suffered range depletion and local extinction through altered land management practices or land use changes. Even the most common species of lowland grassland forbs are now comparatively rare with many locally extinct or near extinct in the greater Melbourne area.

Forbs, or wildflowers as many people call them, are undoubtedly the showy part of lowland grasslands. A more significant ecological consideration is that forbs play a very important role in maintaining the biodiversity and overall health of these systems. Most notably, they provide habitat and food for a range of both common and threatened grassy ecosystem animals, including insects and other invertebrates (Kaufman *et al*. 1998, Yen 1999).

There is general concern about the survival and recruitment of forbs in lowland grasslands (Cropper 1993, Morgan 2000). Sporadic or non-existent recruitment in the wild has been noted by several authors (Barlow 1998, Morgan 1998 and 2000, Henderson and Hocking 2000). Morgan (2001) demonstrated low levels of recruitment of native forbs species over a period of four years in Victorian Grasslands with various management histories. In comparison, much of the work on tall-grass prairie in the United States of America has shown there is good recruitment of forbs provided conditions are appropriate (Knapp *et al*. 1998).

Some factors to consider

The various reasons for the lack of recruitment of forbs have been the subject of a number of unpublished investigations (Henderson and Hocking 2000). Reasons for lack of recruitment generally sited include a lack of a thorough understanding of the particular life histories of the individual plants or lack of appropriate vegetation management regimes. Due to lack of success, many of these studies have not been reported in the scientific literature (Lunt 1997, Morgan 1998, Craigie and Hocking 1999). Recent advances in our understanding of ecological processes involved in competitive plant growth in grassy ecosystems point to a number of factors which require investigation (Gibson 1989, Gibson and Hulbert 1987, Morgan 1995a, Henderson and Hocking 1998, Wijesuriya and Hocking 1998). These include soil fertility in relation to soil disturbance, timing of management intervention and stimulation of flower and seed production through grazing and soil-stored seed banks.

Individuals of many forb species are generally long-lived, reproduce vegetatively and produce copious amounts of germinable seed (Morgan 1999a, Clarke *et al*. 2000) It is clear from recent studies by Morgan (1998 and 1999b) and Robinson (2003) that seedlings planted into field conditions are capable of maturation. Unfortunately, in the case of Morgan (1999) there was little seedling recruitment from these planted stock. More recent unpublished work by the author, presented here, may explain, at least partially, some reasons why recruitment is failing. While annual germination and recruitment may not be critical to many grassland plants periodic germination and recruitment is necessary to maintain population genetics and dynamics in the long-term. The continued existence and ongoing recruitment of lowland grassland forbs is essential for the long-term survival of these critically endangered grasslands in south-eastern Australia (McIntyre *et al*. 1995). The role of germinability, herbivory and some soil conditions are here investigated as key factors in effecting recruitment.

Germination

While many grassland forbs are not recruiting well in the field, many would appear to be relatively easy to germinate and grow under nursery conditions Many years of work has been carried out in nurseries to raise native forb species from seed for use in a range of rehabilitation and revegetation applications. Most plant growers have had similar glasshouse experiences to DeKock and Taube (1991), Willis and Groves (1991), Morgan (1999) Clarke *et al*. (2000) and Robinson (2003). All of which show that provided there is sufficient moisture and appropriate temperature regimes, germination is both rapid and for many species unspecialized. These growers commonly used temperatures that are know to stimulate germination in other cultivated species, namely 20°C during the day and 12–15°C at night. These temperatures relate to very limited periods under field conditions, namely mid-spring and mid-autumn in lowland south-eastern Australia (records of the Bureau of Meteorology, Victoria). These same forb species are highly responsive to regular moisture and addition of plant fertilizers. Glasshouse conditions are however, considerably different to natural ecosystems where conditions are unpredictable and uncontrolled.

There is a range of forbs that are genuinely problematic or have specialized germination requirements, most notably members of the families Apiaceae, Fabaceae, Ranunculaceae and some Asteraceae (Ralph 1997, The Australian Daisy Study Group 1983). Some of these difficulties relate to the need for after-ripening, leaching, hard seed coats, stratification or exposure to light to stimulate germination (Plummer *et al*. 1994). The application of heat (to simulate the effects of fire) is widely used to trigger germination in members of Fabaceae, Mimosaceae and some *Dianella* species. Research into the use of smoked water to stimulate germination is receiving increased attention for many problematic species or to 'improve' germination in grasses (Read and Bellairs 1999) and a range of other species (Dixon and Roche 1995). Cold stratification of seed, although not widely recognized in lowland grassland plants, is increasingly being recognized as important for a range of species notably *Bursaria*, *Hymenanthera*, *Eryngium*, *Microseris* and *Brunonia* (R. Robinson personal observation).

While generalizations about specific germination characteristics can be made, in reality, these characteristics may vary markedly between species and most notably between populations (Morgan and Lunt 1994).

Herbivory

Herbivory is well documented for its effect on the recruitment of forbs species (Chalmers 1995). Grazing animals, including insects and other invertebrates, are a major influence on recruitment and competitive dynamics in vegetation. Major changes in the faunal composition and types of grazing in grasslands have occurred since European settlement with local extinctions of many native vertebrate species and replacement with introduced species (Lunt *et al*. 1998). Introduced herbivores both vertebrate and invertebrate have come to dominate many grassy ecosystems in south-eastern Australia (Yen *et al*. 1994, McIvor and McIntyre 2002).

Much research effort has been expended in agricultural systems to understand the effects of invertebrate herbivory on the recruitment of seedlings in commercial crop species. Introduced red-legged earth mites (*Halotydeus destuctor*) and blue oat mites (*Penthaleus major*) have been shown to kill up to 86% of emerging seedlings in the introduced forbs canola, sub-clover, lucerne and several other crops (Liu and Ridsdell-Smith 2000). These two introduced species of mite have been observed feeding in large numbers on a range of native forb species including *Craspedia*, *Kennedia*, *Podolepis* and *Senecio* (R. Robinson personal observation).

The effects of rabbit grazing on seedling establishment are very well documented, especially in Mediterranean-type climate ecosystems of the world. Recent studies have strongly indicated that even low numbers of rabbits can have considerable impacts on individual plant species (Auld 1995, Norbury and Norbury 1996, Edwards and Crawley 1999). Large vertebrate grazing is widely recognized to have a significant impact on the structure and dynamics of grasslands (Collins and Benning 1996, McIvor and McIntyre 2002). Management of biomass and canopy cover through grazing or fire is generally viewed as essential to maintenance of biodiversity in grassland (Gibson *et al*. 1993, Henderson 2002, McIvor and McIntyre 2002). Introduced grazing animals are viewed as having considerable impact on structure, floristics and recruitment dynamics of grassland in lowland south-eastern Australia (Henderson and Hocking 1998, Lunt *et al*. 1998, Henderson 2002).

Soil disturbance

Soil disturbance within lowland grassland is generally viewed as being detrimental to species composition, particularly in relation to weed invasion (Phillips and Hocking 1996). Recent studies have identified nutrient release from decomposing plant material following soil disturbance as a key factor driving weed growth (Wijesuriya 1999). Conservation managers have been implored to 'minimize soil disturbance' (Barlow 1998) with this mindset driving much grassland management over the past two decades.

Small-scale patch soil disturbance has been shown to be important to the overall dynamics of a range of ecosystems (Gibson 1989, Pyrke 1994). Small-scale disturbance at the microsite level may be a critical factor in the maintenance of the diversity and species composition of lowland grassland. Major shifts in species composition or loss of plant species diversity may be partially attributable to reduced small-scale animal disturbance, namely biomass reduction and the creation of canopy gaps (Hitchmough 1996, Morgan 1998b), creating suitable conditions for germination and establishment of some of the forb species. The nutrients released following disturbance identified in studies by Wijesuriya (1999) as being advantageous to weed growth may be similarly advantageous to native forb recruitment and growth.

A case study in forb establishment

A study into the recruitment dynamics of some grassland forbs was carried out by the author (Robinson 2003). This case study presents some of the information gleaned from that investigation.

The study site was located at the Iramoo Wildlife Reserve, adjacent to Victoria University, St. Albans, Victoria (144°50′00″E, 37°45′00″S). The Iramoo Wildlife Reserve is approximately 37 ha and adjoins a smaller (10 ha) Campus Grassland reserve, with other connections via habitat corridors to several small grassland reserves. St. Albans is located in the centre of the Keilor Basalt Plains, which lies at the eastern extremity of the larger Victorian Volcanic Plains, which stretches from Melbourne in the east to the South Australia Border in the west.

Several factors were examined including disturbance/lack of disturbance and protection/lack of protection from invertebrates.

Site preparation was seen as key to ensuring the long-term success of direct seeding in heavily weed infested grassland. A specific procedure was developed to remove existing vegetation and assist in depleting the existing seed bank. Site preparation involved the complete removal of existing vegetation. Pre-existing vegetation was composed primarily of serrated tussock (*Nasella trichotoma*), onion grass (*Romulea rosea*) and a range of introduced broadleaved forbs. Seed bank assessments of the site, carried out by Mason (2002) indicated large numbers of potentially germinable seed of several stipoid grasses and broad-leaved herbs.

Atrazine (as Nufarm nutrazine) herbicide was applied at a rate of 8.7 kg ha^{-1} 12 months prior and four months prior to planting. Atrazine was used because this herbicide has been used successfully in a range of grassland revegetation trials (Philips and Hocking 1996, Mason and Hocking 2002). An initial burn was carried out approximately 12 weeks after the initial spray. Standard rate MCPA-dicamba was applied eight weeks prior to planting to remove further germinants of exotic forb species. The entire area was burnt to remove all dead plant material immediately prior to installation of invertebrate exclosures in late July.

An alternative method was used at a site at Cottlesbridge, Victoria. The standing vegetation of this site was composed entirely of introduced annual grasses, primarily large quaking grass (*Briza maxima*) and annual panic grass (*Ehrharta longiflora*). No herbicide was used at this site. A burn was carried out in May followed by shallow-soil disturbance (on disturbance plots) to stimulate germination.

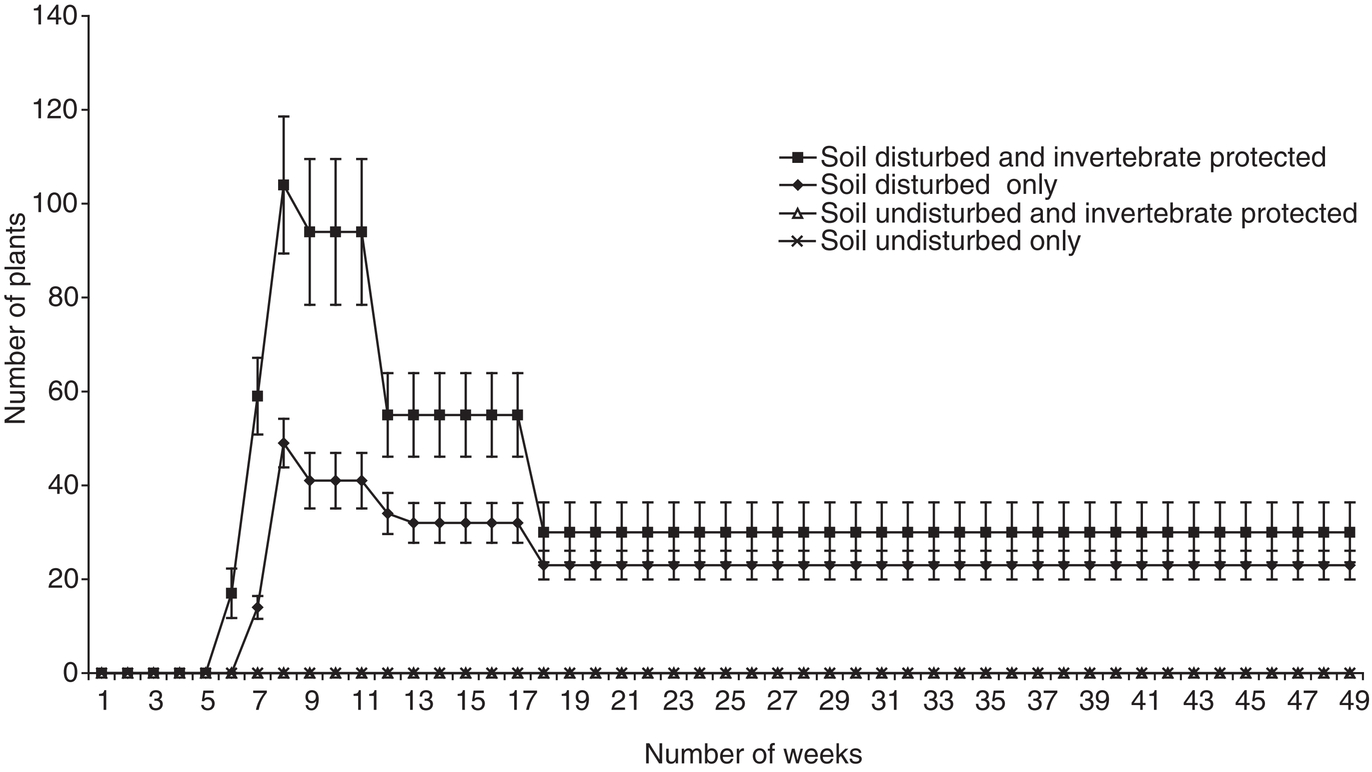

Figure 1. Germination from seed and subsequent survival of *Podolepis* sp. 1 over 50 weeks (n=8).

Twelve weeks later another burn, using a flame gun was carried out to kill germinants. This was followed by a second shallow-soil disturbance to 5 cm (on disturbance plots) after which invertebrate exclosures were installed.

Shallow soil disturbance on the trial plots was achieved by using a small hand-held mattock. Soil was disturbed to a depth of 5 cm. The disturbed soil was lightly levelled by hand with only the largest soil clods broken up. Larger scale implementation trials utilized a rotary hoe set on the shallowest setting.

An equivalent of 300 seed per square metre was sown per trial plot. Seed was hand broadcast over the trial plots followed by a light raking using a steel rake to ensure soil seed contact. One initial watering was carried out to ensure seed was settled into the site and did not blow away. No further watering was carried out. This was not seen as a problem as rainfall in the three months following sowing was predicted to be sufficient for germination.

Results

Recruitment of *Podolepis* sp. 1 plants from seed occurred only in soil-disturbed plots (Figure 1). On soil-disturbed plots, time to first germination from sowing was 5–7 weeks in both invertebrate protected and unprotected plots, after which there was no additional germination. Germination on the unprotected soil-disturbed plots reached a maximum of 12% at week seven with invertebrate protected plots achieving total germination of 26%. Germination in protected plots occurred over a period of three weeks (17 September – 1 October) compared with germination on unprotected sites, which was limited to a two-week period (24 September – 1 October).

Overall survival of plants that germinated from seed in the field on soil-disturbed plots was 46% on invertebrate protected plots and 28% on unprotected plots (Figure 1). Although overall germination on protected plots was 13% higher than on unprotected plots, mortality in protected plots was 71% compared to 53% on unprotected plots. Totals resulting from germination and survival after 50 weeks in soil disturbed treatments were 5% of original germinable seed on unprotected plots and 7% on protected plots.

Recruitment from seed was found to be significantly higher ($P < 0.001$) for *Podolepis* sp. 1 in disturbed soil treatments compared to undisturbed soils. Although there was a trend toward greater survival on invertebrate-protected plots, this was not found to be statistically significant ($P > 0.1$).

Recruitment of *Bulbine semibarbata* plants from seed occurred on both types of soil disturbed treatment plots; that is invertebrate protected and unprotected treatments (Figure 2). There was recruitment from seed on undisturbed soil, but at lower numbers than on invertebrate protected plots. On soil-disturbed plots, time to first germination from sowing was 7–11 weeks after which there was no additional germination. On undisturbed soil and invertebrate protected plots, time to germination from sowing was 9–11 weeks after which there was no additional germination. Germination on the unprotected soil-disturbed plots reached a maximum of 35% germination at week 11 (Figure 2). In comparison, invertebrate protected plots achieved total germination of 51% in the same time period. Germination on protected plots where the soil was not disturbed reached a maximum of 19% total germination after 11 weeks. Germination on disturbed soils occurred over a period of four weeks (1–29 October) compared with germination on undisturbed soils, which was limited to a two-week period (15–29 October).

Overall survival of plants that germinated from seed in the field on soil-disturbed plots was 28% on unprotected plots and 47% on protected plots (Figure 2). Overall germination on soil-disturbed protected plots was 16% higher than on soil-disturbed unprotected plots and mortality in protected plots was lower at 53% compared to 74% on unprotected plots. Mortality was highest (100%) on plots with undisturbed soils protected from invertebrates and was reached by week 17 (10 December). After 50 weeks percentage establishment of the originally sown germinable seed were as follows: 24% on soil-disturbed and invertebrate protected

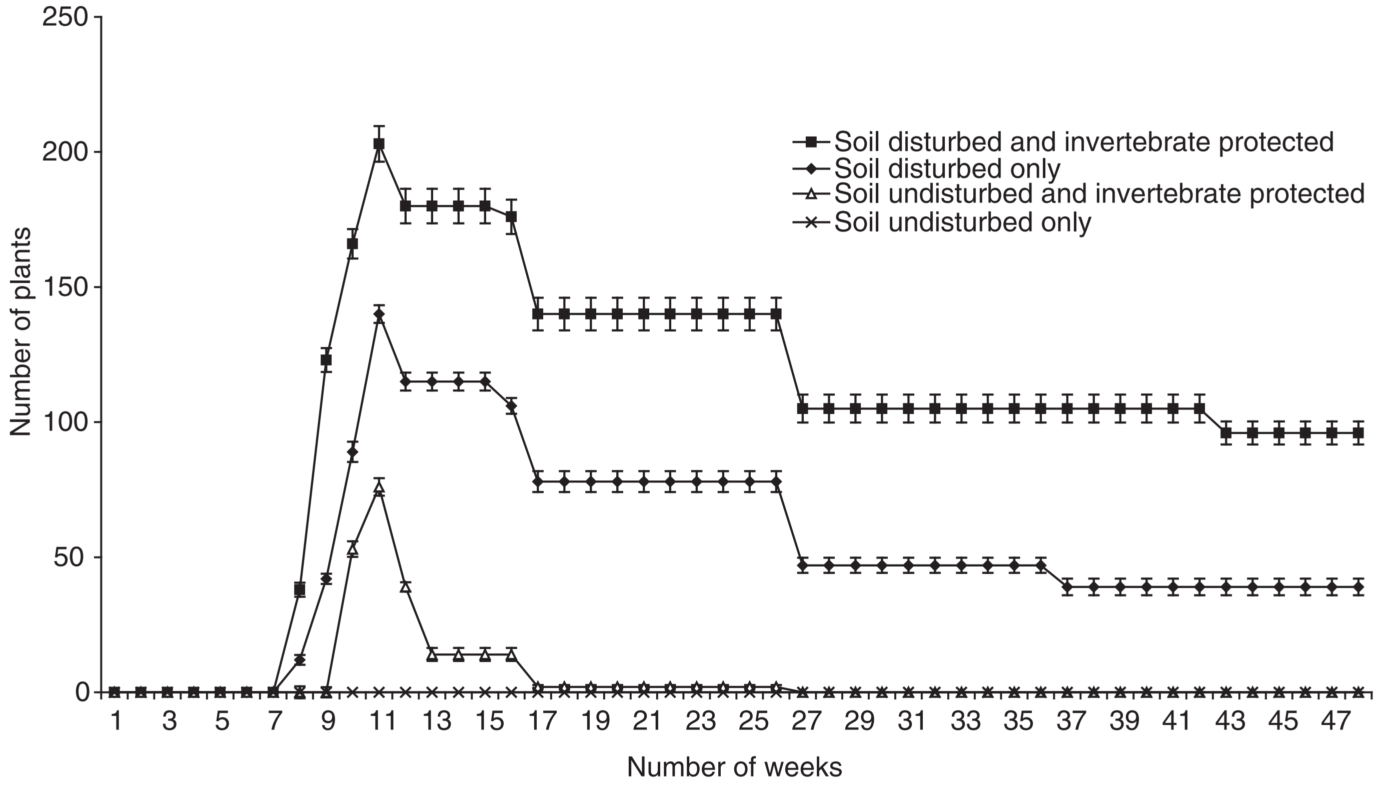

Figure 2. Germination from seed and subsequent survival of *Bulbine semibarbata* (perennial form) over 50 weeks (n=8).

plots; 10% on soil-disturbed only plots and 0% on soil-undisturbed plots and invertebrate protected plots Figure 2).

Recruitment from seed was found to be significantly higher (P <0.001) on soil disturbed plots compared with undisturbed treatments for *Bulbine semibarbata*. Although there was a trend toward greater survival on invertebrate protected plots, this was not found to be statistically significant.

Implementation trials

Further implementation trials were carried out on a range of additional grassland species by staff of the Iramoo Wildlife Reserve (Debbie Reynolds). While results have been variable, sufficient germination has occurred in all species to indicate suitability of the outlined methods for the successful establishment of these species. The species used in the implementation trial included:

Convolvulus remotus blushing bindweed
Craspedia variabilis Billy buttons
Ixiolaena sp. plover daisy
Linum marginale native flax
Microseris sp. 3 yam daisy
Pelargonium australe austral storks-bill
Ptilotus spathulatus pussy tails
Senecio macrocarpus large-fruit groundsel
Velleia paradoxa spur velleia

Discussion

This above study shows that a particular type of disturbance is beneficial to the establishment of *Podolepis* sp. 1 and *Bulbine semibarbata* and suggests that soil disturbance may play a role in the population dynamics of other similar species. These findings must be tempered by the thoroughness of the site preparation and weed control that was carried out.

Small patch soil disturbance has been shown to be important to the overall dynamics of a range of ecosystems (Pyrke 1994, Gibson 1989). Small-scale disturbance at the microsite level may be a critical factor in the maintenance of the diversity and species composition of lowland grassland. Major shifts in species composition or loss of plant species diversity may be partially attributable to reduced small-scale animal disturbance, namely biomass reduction and the creation of canopy gaps (Hitchmough 1996, Morgan 1998b), creating suitable conditions for the germination and establishment of some of the forb species. The nutrients released following disturbance identified in previous studies (Wijesuriya 1999) as being advantageous to weed growth may be similarly advantageous to native forb recruitment and growth.

Removal of vegetation cover that involves disturbing the soil in grassy ecosystems in Australia is presently viewed negatively in the popular and scientific literature (McIvor 2002, Henderson and Hocking 1998, Lunt *et al*. 1998) due to weed invasion attributed to disturbance in some grassy ecosystems. This study suggests that soil disturbance, as part of native vegetation management may be useful to conservation and management of lowland grassy ecosystems under the current environmental conditions.

The implications for weed invasion of removing of above-ground competition, namely massive recruitment of exotic species, may provide some sort of indication of the recruitment requirements of native forb species. Studies into the biology of weeds in Australia indicate a need for what is generically termed 'disturbance' (Groves *et al*. 1995, 1998). In many instances 'disturbance' relates directly to exposure to light through reduced competition e.g. (*Senecio madagascariensis* Sindel *et al*. 1998) or alterations in nutrient availability (Wijesuriya and Hocking 1998).

Soil disturbance as an isolated factor may not explain the clear distinction in performance between the various treatments in the above study. Soil seed contact may also play a significant role in germination. The seed of both *Podolepis* sp. 1 and *Bulbine semibarbata* do not have the specialized means to 'drill' seed into the soil, a characteristic exhibited by some members of the Poaceae (*Themeda*, *Austrostipa*, *Austrodanthonia*) and Geraniaceae (*Pelargonium*, *Erodium*). Unspecialized seed may need to be incorporated into the soil by disturbance before germination is effected.

Germination of seed of *Bulbine semibarbata* did take place on undisturbed soils protected from invertebrates but these seedlings did not survive. This may indicate that at least for *Bulbine semibarbata* the degree of burial may not be an issue and that ability of the radical to penetrate the lower layers of the soil may be more important. Recent studies of the germination of grain crops suggest that humidity may play a more significant role in germination than soil-seed contact (Wuest *et al.* 1999). Protection of the seed by solid invertebrate barriers may have altered humidity and temperature levels at ground level therefore exhibiting an influence on germination. Similarly, soil disturbance may provide sufficient microtopographical relief in the soil surface to facilitate seed to occupy small pockets in the soil surface that would provide the higher humidity to allow germination.

Herbivory is increasingly seen as important to survival or otherwise of grassland forb species and was shown to influence recruitment or establishment of *Podolepis* sp. 1 or *Bulbine semibarbata* in this study. Further investigation would be needed to establish the full effect of herbivory on the recruitment, survival of germinants and population dynamics of *Podolepis* sp. 1 and *Bulbine semibarbata*. The slightly unusual weather conditions of the study period (few, heavy rainfall events with extended dry periods between) and the thoroughness of the site preparation, may have partly suppressed the effects of invertebrate herbivory.

The thoroughness of the preparation of the site before the trials may also help to explain other possible mitigating effects on recruitment in grassland forbs, and in particular, the absence of competition or swamping by competing seedlings. Soil seed bank analysis by Mason (2002) carried out on trial plots adjacent to the study site (within 10 m) indicates high levels of soil stored seed of several introduced species, namely Chilean needle grass (*Nasella neesiana*) and serrated tussock (*Nasella trichotoma*) and several dicot forbs. Total numbers of seed were high in Mason's parallel study, reaching 7000 per square meter for Chilean needle grass and 14,000 per square meter for serrated tussock. The repeated herbicide treatment of the study site, in addition to removing existing plants, may have depleted the soil stored seed of most species in the soil-stored seed bank by repeated stimulation of seed and removal of germinated plants. Throughout the study period very few seedlings, other than those purposely sown for the trial, germinated in the trial plots. Testing specific manipulation of disturbance and herbivory coupled with varying levels of soil-stored seed bank depletion may prove useful in simulating actual field conditions.

Conclusion

The creation of suitable microsites for the recruitment of native forbs in lowland grassy ecosystems is essential to ensure success. This process may be complicated by the presence of introduced species that may or may not have similar germination and recruitment requirements. The build-up of soil-stored seed banks composed largely of introduced species may further tip the balance in favour of introduced species. Further study will need to be carried out to elucidate the conditions which promote or inhibit the germination and survival of both native and introduced forb species.

The presence of introduced herbivores and the lack of native animals in many grasslands may disadvantage the recruitment of native forbs. Reduction of introduced herbivores, particularly invertebrates may give forbs a window of opportunity to establish seedlings.

The usefulness of soil disturbance in the restoration of grassy ecosystems is not generally recognized. The use of techniques such as those used in this study indicate that thorough site preparation including creating appropriate soil conditions is significant. The full study carried out by Robinson (2003) showed that shallow soil disturbance greatly enhanced germination as well as survival of juvenile and semi-adult plants.

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Footnote

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