

VICTORIA UNIVERSITY OF TECHNOLOGY



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NATURAL RECRUITMENT OF NATIVE FORBS IN THE GRASSY ECOSYSTEMS OF SOUTH-EASTERN AUSTRALIA

Thesis for Master of Science

By

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Natural recruitment of
native forbs in the grassy
ecosystems of south-eastern

As for many lowland grassy ecosystem forbs in South-eastern Australia, the recruitment dynamics of the grassland forbs *Podolepis* sp. 1 sensu Jeanes 1999 (Basalt *Podolepis*) and *Bulbine semibarbata* perennial form (Leek Lily) are unknown. *Podolepis* sp. 1 and *B. semibarbata* were used as models of recruitment for a range of similar forb species.

In vitro trials of *P. sp. 1*, *B. semibarbata* and an additional 16 grassy ecosystem forb species assessed germinability, germination lag time, germination speed and duration of emergence in relation to light and dark treatments. *In vivo* trials assessed recruitment from seed as well as field survival of several age classes of transplants, and how these were affected by soil disturbance and invertebrate herbivory over a 50-week period. *In vitro* germination for most species was unspecialised with germination rates greater than 50 percent. Light was a significant or neutral factor for the majority of species but negatively affected several. Survival of juvenile and semi-mature plants of *P. sp. 1* and *B. semibarbata* were achieved in the field, along with high levels of recruitment from seed in some instances, overcoming previous lack of success in recruitment and survival of these lowland grassy ecosystem forb species. Both recruitment from seed and survival of juveniles was markedly higher in soil-disturbed plots compared with undisturbed plots. Protection from invertebrates generally enhanced survival of seed-recruited seedlings, planted juvenile plants and semi-mature plants, especially in soil-disturbed plots.

The possible reasons for high recruitment and survival of *Podolepis* sp. 1 and *Bulbine semibarbata* (perennial form) in soil-disturbed and invertebrate-protected plots are discussed, along with the implications of these techniques for recovery and conservation of lowland grassy ecosystem forb species in South-eastern Australia.

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Declaration

This thesis is my original work and has not been submitted in whole or in part, for a degree at this or any other university. Nor does it contain, to the best of my knowledge and belief, any material published or written by another person, except as acknowledged in the text.

Randall William Robinson

1.1 *Summary of context: Relieving an evolutionary bottleneck.*

Lowland grassy ecosystems in south-eastern Australia have undergone massive decline and alteration since European colonisation in 1788. Of particular concern is the continued decline of forbs. Of the approximately 1000 species of native forbs, 200 are considered rare and endangered with many more suffering rapid declines in recent years.

Because many grassland forb species are long-lived and not totally reliant on recruitment from seed, the presence of existing plants gives the impression that healthy populations of these plants exist. Increasing awareness of the genetics, recruitment and dynamics of populations is showing that at least some of the assumptions about ecosystem health, based on visual assessment, are in fact erroneous or simplistic. Emerging knowledge suggests that many of the existing plants found in lowland grassland may, in fact, be very old. What we have traditionally viewed as populations may be very old individuals or at best a few plants. The problem is analogous to long-lived animal species that are not replaced by offspring. Once the old individuals die they are not replaced, leading to the eventual erosion of genetic diversity, extinction of populations and subsequently loss of the species.

The failure of many grassland forb species to recruit from seed in the wild is seen as a major impediment to the conservation and restoration of these species, and lowland grasslands as a whole, in the long-term.

Little work has been carried out on recruitment of lowland grassland native forbs in their natural state and much of this is confined to a few endangered species. Extensive restoration works in lowland grassland are at present reliant on the use of nursery grown stock to re-establish species in the wild. The use of nursery grown stock is expensive, labour intensive and applicable only to small-scale restoration, but is not suitable to the requirements for

broad-scale restoration. Critical assessment of the success or failure of present restoration works has yet to be carried out.

The present gap in knowledge in relation to the recruitment of native forbs in the wild is a serious impediment to the conservation and restoration of the component species of lowland grasslands and of the grassland communities. A thorough understanding of the processes of recruitment in the wild could lead to cost effective restoration works and contribute to effective conservation of lowland grassland in South-eastern Australia.

1.2 Overall aim of the study

To determine at what life stage or stages recruitment is failing and why, and to determine the germination requirements and influences to overcome recruitment failure of selected native forbs.

1.3 Research approach

The research investigated some key stages in the recruitment process under laboratory and field conditions.

1.4 Species selected

Basalt Podolepis (*Podolepis* sp. 1) and Leek Lily (*Bulbine semibarbata* (perennial form) were selected for use in field trials. These two species are representative of two of the major plant families represented in lowland grassy ecosystems: Daisies (Asteraceae) and Lilies (Asphodelaceae). The life form of these plants and their life histories are seen as being indicative of a range of similar large-seeded herbaceous plant species. Additional species were used in the laboratory germination tests. These additional plant species were chosen as they represent species used in restoration projects or species that would be used in restoration projects if their germination and recruitment requirements were known. The additional species included in the germination

trials represent species from a range of grassy ecosystems that are currently the subject of concerted restoration effort.

Possibly more appropriate species could have been chosen but sufficient seed was not available to use these at the time of the trials. The seed of *Chrysocephalum appiculatum*, the species originally chosen for this study, was found to be heavily predated by seed eating insects resulting in mostly unviable seed. All seed of *Bulbine bulbosa* purported to come from the basalt plains proved to be misidentifications of *Bulbine semibarbata* (perennial form) or *Bulbine glauca*.

1.5 Germinability

The ability or lack of ability of seed to germinate is seen as a primary source of potential failure in the recruitment process. Of the forb species investigated by other authors most have not shown any particular problems (DeKock and Taube, 1991, Watson, 1995) but most studies have used wild populations with known ability to set seed. Lack of ability to germinate could be attributed to several causes including lack of viability due to unsuccessful pollination, failure of seed to develop and mature, predation, or specialised conditions needed for germination. A range of native forb species are known to have specialised needs for germination such as smoke (Read and Bellairs, 1999), heat or chilling (Ralph, 1997)

Germination tests were carried out to determine the ability of apparently viable seed to germinate. These tests were seen as essential to rule out specialised needs for germination as a potential inhibitor to recruitment. Using standard seed testing techniques, germination was carried out under laboratory conditions that mimic assumed germination temperatures in the field based on past germination studies (Morgan and Lunt, 1994, Watson, 1995 and Willis and Groves 1991).

1.6 *Life stage*

Anecdotal evidence suggested that some individuals may have been germinating in the field but not reaching maturity. Alternatively, it had been established for some species that mature plants transplanted into field conditions had the ability to survive but fail to recruit new plants. There was a need to determine at what stage in the life cycle of the plant recruitment was failing. Recruitment failure may happen at different life stages or at several life stages. Determining at what stage or stages recruitment was failing was seen as critical to focus future work.

Trials were carried out to determine at what life stage or life stages recruitment was failing and the potential reasons for this failure. Seed and various sized plants were planted under a range of field conditions and their progress monitored.

2.0 Background

2.1 Lowland grassland a threatened ecosystem complex

Lowland Grassy Ecosystems (native grasslands and open grassy woodlands) are some of the most endangered ecosystems in Australia (Kirkpatrick *et al.*, 1995). For example, Western Volcanic Plains Grassland has been reduced to 0.05% of its former extent with continuing depletion identified as a major conservation issue (DNRE, 1999). The State Government of Victoria has afforded protection to Plains Grassland under the Flora and Fauna Guarantee Act 1988 (DNRE - Dept Natural Resources and Environment Action Statement No. 53). This and the other lowland grassland communities are currently under consideration for listing under the new national Environment Protection and Biodiversity Conservation (EPBC) Act 2000. Several of the plants and animals of Plains Grassland are accorded protection under both the State and Federal acts (DNRE, 1998; EPBC, 2000).

Approximately two hundred species of forb that occur within the lowland grassy ecosystems of south-eastern Australia are listed as rare and endangered (Ross 2000; Commonwealth of Australia 2000). Many of these species were formerly widespread and abundant but have suffered range depletion due to agriculture, urbanization and altered land management. In addition to being an important biodiversity component in grassy ecosystems, forb species provide habitat and food for a range of threatened grassy ecosystem animals, including an abundance of insects and other invertebrates (Kaufman *et al.* 1998, Yen 1999). Recruitment of the component forb species is one factor that is essential for the long-term survival of the critically endangered lowland grassy ecosystems of south-eastern Australia (McIntyre *et al.* 1995).

2.2 *Lack of recruitment of grassy ecosystem forbs*

There is a long-standing and widespread concern about the recruitment of many of the forb (wildflower) and sub-shrub species in lowland grassy ecosystems (Cropper 1993, Morgan 2000). Recruitment of many of these plants in grassy ecosystems is sporadic or non-existent in the wild (Barlow, 1998; Morgan, 1998b; Morgan, 2000; Henderson and Hocking, 2000). Morgan (2001) demonstrated a very low level of recruitment of native forb 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).

In contrast, most of the non-recruiting Australian lowland grassland forb species are relatively easily grown under nursery conditions (Allen and Franke pers. comm.). Individuals of these non-recruiting species are generally long-lived 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 from practical experience in a number of extensive restoration works that seedlings planted into field conditions as tubestock are capable of maturation. It is also clear from these same experiences that although planted stock will persist for 10-15 years there is little recruitment of seedlings from established stock.

The reasons for the lack of recruitment of forbs in the wild have been the subject of a number of unpublished investigations, largely without success (Henderson and Hocking 2000) mainly attributable to the lack of a thorough understanding of the individual life histories of the plants involved or the appropriateness of vegetation management regimes used. Due to the lack of success, many of these studies have not been reported in the scientific literature (Craigie and Hocking, 1999; Morgan, 1998b; Lunt, 2000). 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 1987, 1989; Henderson and Hocking,

1998; Morgan, 1998a; Wijesuriya and Hocking, 1998) namely soil fertility in relation to soil disturbance, timing of management intervention, stimulation of flower and seed production through grazing and the importance of soil-stored seed banks. It is the intention of this project to investigate a number of these factors including disturbance, herbivory and management practices.

There is little information regarding the natural recruitment of native perennial forb species in grassy ecosystems in south-eastern Australia. Pyrke (1994) recorded a suite of species colonising animal disturbance in forested areas of Tasmania. Surveys carried out by Morgan (1998a), Henderson and Hocking (2000) and Lunt (1990) recorded evidence of occasional recruitment but did not explain the triggers or restrictions to recruitment. Experimental studies by McIntyre (1990) and McIntyre *et al.* (1995) examined germination and disturbance responses in some herbaceous species. Other examples of studies that include some consideration of factors important for recruitment are reviewed in section 2.3 to 2.7.

There are numerous examples worldwide of recruitment of individual species in grassland or grassy woodland communities in Mediterranean-type (mild damp to wet winter, warm to hot dry summer) climate ecosystems. Considerable work has been done on Tall-grass prairie ecosystems in the USA (Baskin and Baskin, 1988; Knapp *et al.* 1998) and calcareous meadows in England and Europe (Grimes *et al.* 1981). These northern hemisphere examples deal with northern temperate climate grasslands with somewhat dissimilar climatic conditions to those in south-eastern Australia although some of the ecological processes and interactions appear to be similar. Of particular relevance are studies by Gibson (1997, 1999) that indicate soil disturbance coupled with removal of competition plays a major role in establishment of prairie forb species.

Existing information regarding recruitment of forbs in natural systems in south-eastern Australia applies mainly to critically endangered species (Gilfedder and Kirkpatrick 1994; Morgan, 1995a). Some ecological information can be deduced from these previous studies that can be directly applied to generalist

species that are at present widespread but still suffering from inadequate recruitment. Lunt (1990) recorded limited recruitment of some native species following autumn fire in previously grazed but unburnt grassland. He speculated that many of these species may have been present as mature but hidden plants in grazed vegetation which regenerated vegetatively following fire. Several species were, however, recorded as regenerating from seed, but because of the limited nature of the recruitment (and because the data were from one site only), the research did not allow any definitive conclusions to be drawn regarding recruitment from seed.

2.3 *Moisture and seasonal variability*

Flannery (1994) describes longer-term weather cycles and their effect on the Australian biota, and strongly correlated the influences of El Nino and La Nina to ecological responses, including germination and recruitment of plants. Broad speculation can be implied from Flannery (1994) but a finer scale more appropriate to management, it is recognised that some plants seed and recruit in cycles of greater than one year or germinate in response to certain climatic conditions that have an episodic occurrence (Borchert et al. 1989). Avery (1933) related the germination of *Nicotiana* (Tobacco) species to higher moisture levels which breaks seedcoat induced dormancy. This has been demonstrated in *Nicotiana suaveolens*, which had mass germinations in the wetter than average springs of 1984, 1988, 1993 and 2000 at Yarra Bend Park, Melbourne (personal observation).

Stochastic events such as flood and drought are known to affect the magnitude of germination events in a range of species of forbs and other herbaceous plants including *Antirrhinum* (Salisbury, 1961) and *Vulpia* spp. (Cousens and Mortimer 1995). Various forb species in grassy ecosystems in south-eastern Australia have been observed flowering or seeding well in some years but not in others but this has not been related to recruitment. It is widely assumed that recruitment is related to climatic variables, particularly rainfall,

but this has not been definitively correlated to moisture or temperate regimes in forbs in south-eastern Australia. Records of recruitment in the field are few (Lunt, 1990; Morgan, 2001) and not related to climatic variables.

Much work has been carried out in nurseries (Victorian Indigenous Nurseries Co-operative, Wyeena Nursery) to raise native forb species from seed for use in a range of revegetation applications. Most plant growers have had similar glasshouse experiences to DeKock and Taube (1991), Willis and Groves (1991), Morgan (1999) and Clarke *et al.* (2000), all of which show that provided there is sufficient moisture and appropriate temperatures, germination is both rapid and for many species unspecialised. These growers commonly use temperatures that are known to stimulate germination in many cultivated species, namely 20 degrees Celsius during the day and 12-15 degrees Celsius 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). Similarly, these same forb species are highly responsive in growth 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 specialised germination requirements, most notably members of the families Apiaceae, Fabaceae, and some Asteraceae (Ralph 1997; The Australian Daisy Study Group 1983). An after-ripening period and/or need for exposure to light before germination will take place are known in a range of species including members of the Asteraceae (Plummer *et al.* 1994). The application of heat (to simulate the effects of fire) is widely used to stimulate germination in members of the Fabaceae, Mimosaceae, and some *Dianella* species. Research into the use of smoked water to stimulate germination is gaining increased attention for many problematic species or to 'improve' germination in grasses (Read and Bellairs (1999) a range of other species (Dixon and Roche, 1995). Cold stratification of seed is not widely recognised in lowland Australian plants but

is increasingly being recognised in a range of species notably *Bursaria* (Franke 1993) and *Eryngium*, *Microseris* and *Brunonia* (personal observation)

Germination characteristics vary markedly between species and most notably between populations (Morgan and Lunt (1994)). It is impossible to predict the specific responses or needs of a given population to light, moisture or temperature although it would appear that there are general trends that can be observed.

2.4 *Trophic cascades*

Lowland grassy ecosystems have suffered mass localised extinctions of native animals (Lunt *et al.*, 1998, Bennett *et al.*, 1998). These animals provided a range of what is known as 'ecosystem services' including grazing, digging, controlling populations of other animals, dispersal of propagules and nutrient cycling.

Diamond (1984) invoked the term 'trophic cascades' to explain the way in which the removal of certain 'keystone species' can have major impacts at various trophic (food chain) levels within ecosystems and lead to severe alterations in plant recruitment. One example given by Diamond was of the genus *Hibiscadelphus*, a genus of long-lived, presently non-recruiting woody plants in the Hawaiian Islands. Bird malaria was introduced to Hawaii along with the mosquitoes that transmit it. Honeycreepers, a type of nectar feeding bird were eliminated across the introduced range of the mosquito due to their susceptibility to bird malaria. *Hibiscadelphus* were reliant on the Honey Creepers for pollination. *Hibiscadelphus* is now extinct or nearly extinct from lack of pollination and seed set. The experience with *Hibiscadelphus* would seem to parallel the situation for some apparently non-recruiting native perennial forb species in Australia. However, the impact of the removal of keystone animal species on forb species in Australia is not documented but speculated. Other mechanisms facilitating recruitment that are likely to be

absent from these present grassy ecosystems, that would have been provided by animal species, include particular types of soil disturbance, nutrient cycling and seed dispersal presumably not effected by introduced animals.

Gott and Conran (1998) highlight the role and potential impact of large numbers of pre-European humans on the ecosystems of Australia. The removal of an entire population of people and their “management” or at least their role in the ecosystem and their replacement with a different style of management is likely to have a major impact on the functioning of that ecosystem. It is impossible to know what the pre-European role humans played in the ecosystem and what essential processes they provided. It is known that fire, soil disturbance and propagule dispersal are broad ‘ecosystem services’ provided by pre-European humans in the grassy ecosystems of south-eastern Australia.

Recent studies in the northern hemisphere on recruitment of plant species in relation to soil nutrient levels have shown a clear correlation between the success or failure of recruitment and the distribution of nutrients in soil (Wijesinghe and Hutchings, 1999; Farley and Fitter, 1999). These studies focused on homogeneity and heterogeneity of forest soils and responses of certain plant species to these conditions. These studies determined that strongly heterogeneous soils favoured plant growth. Their work also found that highly concentrated patches of nitrogen (in the form of animal faeces) favoured recruitment and affected distribution and growth form of some plant species. Further work carried out by Hodge *et al.* (1999) showed more explicit examples of the effects of soil nutrient distribution heterogeneity on plant growth, flowering and seeding. Their results clearly showed that plants performed better in situations with localised concentrations and uneven distribution of nutrients (e.g. animal faeces) in the soil profile.

If there has been a 'trophic collapse' similar to that outlined by Diamond (1984), and as implied in Lunt *et al.* (1998) it would follow that a range of plant species would have their ability to reproduce or recruit removed or greatly reduced. One aspect of 'trophic collapse' could be the absence of vertebrate

and invertebrate animal faeces coupled with an associated decrease in heterogeneity in soil structure resulting from lack of particular types of soil disturbance.

2.5 Soil disturbance

With the general absence of native vertebrate animals from most grassland remnants many of the 'ecosystem services' provided by these animals are also missing or altered by introduced animals. Most relevant for recruitment (assuming adequate seed set and viability) is the effect of creating suitable soil conditions for germination and growth. Some grassy ecosystems areas do still contain an abundance of animals. However, these assemblages would have declined or been modified in composition since settlement. Many forb species still persist in some grassy remnants, however these have declined also. Although there have been alterations to both the flora and fauna structure and composition in grassy ecosystems this may not signify a causal link between animal decline and forb decline.

Morgan (1998a) and Clarke *et al.* (2000) suggested that many lowland grassland plant species that are not recruiting well in the wild would germinate quite readily, rapidly and with relatively high germination rates under controlled but unspecialised glasshouse conditions. These studies would suggest combinations of factors in addition to the ability to germinate in the wild may prevent recruitment. These may include a lack of soil stored seed banks, genetic difficulties and inappropriate management regimes.

A study by Pyrke (1994) of the configuration of the diggings of echidna and other small mammals in Tasmanian grassy ecosystems documented the plant species that germinate in and around these diggings. This study found germination of native plant species but also a difference in preference between species, some germinating on the loosed soil around the hole and some in the basin created by digging. Similar findings are recorded in North

American tallgrass prairie by Gibson (1989). Gibson's work is particularly relevant to this project as he found long-lived perennial forb species preferentially recruited on small mammal diggings and disturbed ant mounds.

Trigg (1996 p.156) states that "Echidna scats are long cylinders, up to 2 cm in diameter" and that "They are often found on rock piles and also where the echidna has been feeding; for example, near termite mounds and meat-ant mounds". Similarly, Trigg referred to the scats (animal faeces) of the Eastern Barred Bandicoot, "Bandicoots and the Bilby often deposit their scats near the conical holes they dig while searching for food." These observations strongly suggest that the distribution of scats within the landscape is not entirely random but in at least some cases is likely to be closely associated with physical disturbance by animals. Echidna scats, in particular, are quite large and would provide the concentrated source of nutrients described by Hodge *et al.* (1999) that so affect plant growth. Wijesuriya and Hocking (1998) demonstrated that soil disturbance and associated mineralisation of below ground biomass killed by digging could markedly increase availability of nutrients and soil moisture in Australian lowland grasslands. Soil seed contact is also likely to be enhanced by soil disturbance.

2.6 Herbivory

Herbivory is well documented for its effects on the recruitment of forb species (Chalmers, 1995). Grazing animals including insects and other invertebrates are a major influence on the recruitment and competitive dynamic in vegetation. Major changes in the faunal composition and types of grazing in grassy ecosystems 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 of 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 destructor*) 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 *Wahlenbergia*, *Podolepis*, *Kennedia* and *Senecio* (personal observation).

Work on other invertebrates and their effect on recruitment in grassland is currently being carried out at La Trobe University in Victoria. This work is focussing on snails and slugs, which are known to preferentially graze forb species (Daniells pers. comm.).

The effects of rabbit grazing on seedling establishment are very well documented, especially in the 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). As for much work in this field, most of the studies relate to commercially exploited, introduced or woody species.

Large vertebrate grazing is well documented to have a significant impact on the structure and dynamics of grassy ecosystems (Collins and Benning, 1996; McIvor and McIntyre, 2002). Indeed, management of biomass and canopy cover through grazing or fire is generally viewed as essential to maintenance of biodiversity in grassy ecosystems (Gibson et al. 1993; Henderson, 2002; McIvor and McIntyre 2002, page 16). Grazers, grazing regimes and types of grazing have changed considerably since European settlement of Australia and this is viewed as having considerable impact on the structure, floristics and dynamics of grassy ecosystems in lowland south-eastern Australia Lunt et al. 1998; Henderson and Hocking 1998; Henderson 2002;.

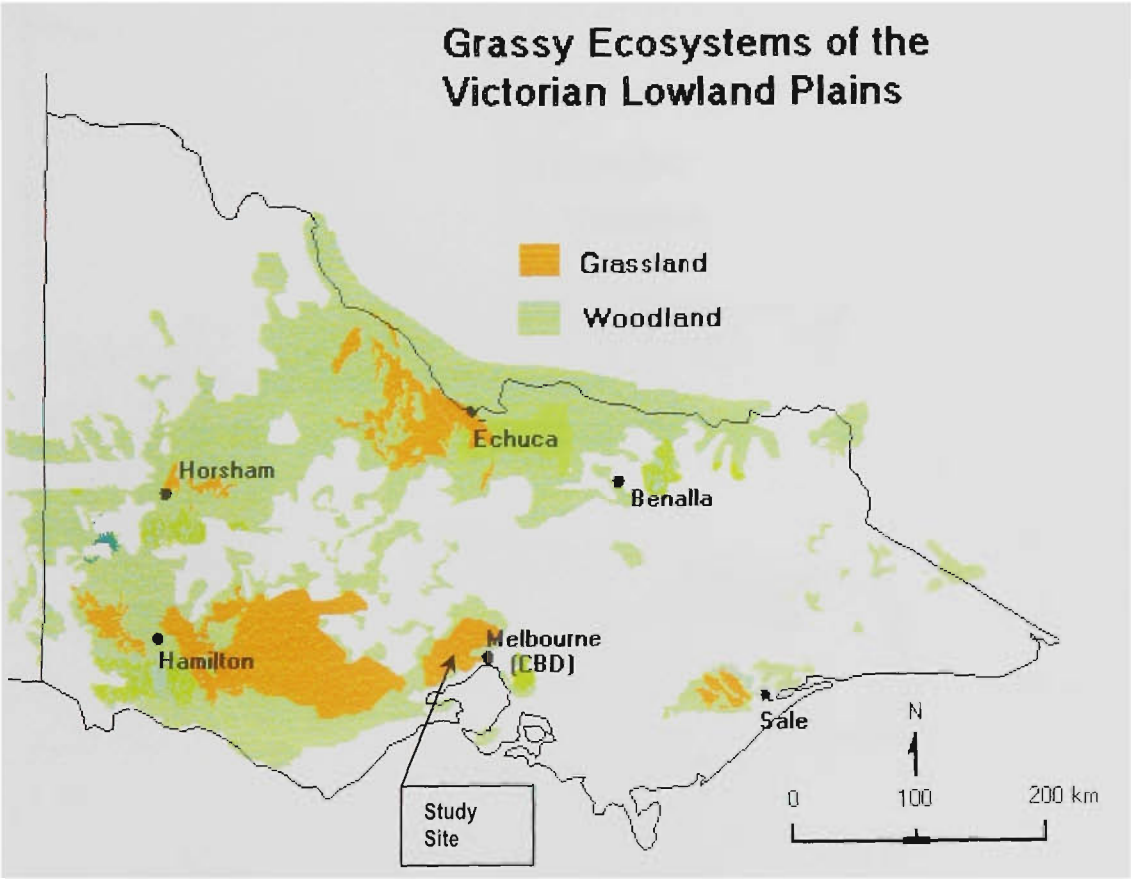
2.7 Light and dark

The effect of light and dark on the germination of grassy ecosystem plants has been investigated by grassy ecosystem investigators (Willis and Groves 1991; Morgan 1998, and Clarke *et al.* 2000). A considerable amount of data has been collected in regard to the light and dark requirements for germination of grassy ecosystem plants. For this project it was considered important to extend research into the germination of grassy ecosystem forb species and to clarify the specific needs of the two main species investigated.

The research reported in this thesis examined critical life stages in the regeneration of Basalt Podolepis (*Podolepis* sp.1) and Leek Lily (*Bulbine semibarbata* perennial form) in relation to light, soil disturbance and herbivory. Light, disturbance and herbivory were viewed as three factors that directly related to management and could be examined under controlled conditions. *Podolepis* sp. 1 and *Bulbine semibarbata* have been chosen as representative of a range of obligate seed-recruiting forb species that were formerly widespread and abundant in lowland grassy ecosystems but have suffered marked decline in recent decades (Lunt et al. 1998). Both species germinate well, and are readily grown, under nursery conditions for some growers but not for others. Clarifying the exact germination requirements will directly contribute to more reliable germination under controlled conditions. The germination requirements of a range of other lowland grassy ecosystem forbs is also investigated. Insights into the recruitment and survival of these species may be directly applicable to other similar species and have particular relevance to the management of existing lowland grassy ecosystems.

3.0 Materials and Methods

The study site was located at the Iramoo Wildlife Reserve, adjacent to Victoria University, St Albans, Victoria (Long. 144° 50' 00" E Lat 37° 45' 00" S). The Iramoo Wildlife Reserve is approximately 37ha and adjoins a smaller (10ha) 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 (Map 1).



Map 1 Location of study site.

(Map provided by Vanessa Craigie Dept. of Sustainability and Environment, State of Victoria)

3.1 Laboratory germination studies

Seed of the species used in this trial was collected at several sites of Lowland Grassland sites centred on St. Albans (Long. 144° 50' 00" E Lat. 37° 45' 00" S) on the Victorian Basalt Plain immediately west of Melbourne, Victoria in January 2000. Additional seed was collected from several sites of Grassy Dry Forest in the Shire of Nillumbik to the north east of Melbourne. The seed of *Leucochrysum albicans* ssp. *albicans* var. *tricolor* was collected from a roadside remnant at Wickliffe in south-western Victoria. Species were selected to compliment previous work carried out by Morgan (1998a).

Table 1 Location of sources of seed for use in germination trials

Name	Location	Longitude	Latitude
<i>Arthropodium minus</i>	Iramoo Wildlife Reserve	144° 47' 41"	37° 44' 28"
<i>Brachyscome diversifolia</i>	Professors Hill	145° 12' 22"	37°43'1"
<i>Bracteantha palustris</i>	Gisbourne Racecourse Wetlands	144° 35'28"	37° 28' 0"
<i>Bracteantha viscosa</i>	Dunmoochin	145° 12' 18"	37° 27' 8"
<i>Bulbine bulbosa</i>	Dunmoochin	145° 12' 18"	37° 27' 8"
<i>Bulbine semibarbata</i>	Radar Hill Woodland	144° 49' 1"	37° 38' 41"
<i>Leucochrysum albicans</i> ssp. <i>albicans</i>	Dunmoochin	145° 12' 18"	37° 27' 8"
<i>Leucochrysum albicans</i> ssp. <i>tricolor</i>	Wickliffe	142° 43' 14"	37° 42' 10"
<i>Microseris</i> sp. 3	Dunmoochin	145° 12' 18"	37° 27' 8"
<i>Podolepis</i> sp. 1	Iramoo Wildlife Reserve	144° 47' 41"	37° 44' 28"
<i>Rhodanthe anthemoides</i>	Organ Pipes National Park	144° 45' 58"	37° 39' 56"
<i>Senecio macrocarpus</i>	Evan Street Reserve	144° 43' 16"	37° 35' 10"
<i>Senecio runcinifolia</i>	Iramoo Wildlife Reserve	144° 47' 41"	37° 44' 28"
<i>Teucrium corymbosum</i>	Plenty Gorge Park	145° 6' 26"	37° 37' 58"
<i>Viola betonicifolia</i>	Humevale Roadside	145° 12' 20"	37° 29' 51"

Seed was dried in paper bags, exposed to Naphthalene to kill invertebrates and then sealed in glass jars and stored at ambient temperatures in an air-conditioned building until used in germination trials 8 months later. Immediately prior to use, seed was sorted to select potentially germinable seed and remove obviously dead seed. Any seeds that appeared damaged, shrivelled or that did not contain embryos were excluded. Seed was determined to be potentially viable if it was solid and intact. No viability tests using tetrazolium were carried out as previous authors have found this method unreliable on some grassy ecosystem species (Lunt 1995).

Germination tests closely followed Morgan (1998). For each individual germination trial replicate, twenty-five seeds were evenly spaced in a grid pattern on a disk of Whatmans #3 seed testing paper in a 9 cm petri dish. Each paper disk was wetted with 5 ml of distilled water and the dish sealed with Labfilm to reduce moisture loss. A total of 100 seeds were used for each treatment. The tests were carried out in Thermoline growth cabinets. Daytime temperatures were set at 20°C, night temperatures at 10°C, with light and dark periods set at 12 hours each. Light was provided by a bank of fluorescent tubes within the growth cabinet emitting a light intensity of 40 microeinsteins m⁻²s⁻¹. For the set of replicates simulating darkness, the set of petri dishes for each species was wrapped in aluminium foil. All replicates in the treatment receiving light were randomly shuffled daily to overcome varying light and temperature levels within the growth cabinet.

Each petri dish was checked daily and germination recorded for the 34 days of the trial. Checking was carried out in low light conditions but not in a dark room. Those species with minimum difference between light and dark treatments may have been affected by low light levels. Germination was judged by the emergence of the radical from the seed coat. Germination of *Podolepis* sp. 1 was determined by the emergence of the cotyledons from the seed coat as these organs emerge prior to radical elongation. Periodically, all germinated seed was removed, moisture levels topped up and the petri dishes resealed.

Several key indicators were used to determine the significance of germination responses to the light and dark treatments applied, including:

- (i) Daily and total percentage germination under diurnal light conditions (**G_{light}**);
- (ii) Daily and total percentage germination under total darkness (**G_{dark}**);
- (iii) Lag time (**LAG**), the period from sowing of seed to first recorded germination. Classification of species into; Very Fast (<7days), Fast (7-14days), Moderate (14-28 days) and Slow (>28days) germinators directly follows Morgan (1998);
- (iv) Germination speed (t_{50}), the period from the sowing of seed to 50% germination of total germination percentage. Classification of species across the categories Very Fast-Slow follows the same scale as listed for Lag time (Morgan 1998);
- (v) Duration of emergence - The period from the start of visible germination (radical emergence) of the first germinant until the last recorded visible germination.

Classification of the life form of the various species follows McIntyre *et al.* (1995) with reference to Morgan (1998a). Seed weights relate only to seed used in the trial and represent an average.

Data were tested for normality and where necessary transformed using either square root or natural log according to Zar (1999) to achieve a more normal population distribution before being statistically compared. A general linear model two-way Anova using Version 11 of SPSS was used. Analysis was subsequently double-checked using the two-way Anova function in Microsoft Excel 2002.

3.2 *Field survivability tests*

The process of narrowing down the stages where recruitment might be failing was seen as critical to focusing future work. Plants were grown in the glasshouse to several key stages in development and planted into the field

under controlled conditions. The narrowing down process was based on key points in the life cycles of the plant that correspond with stages in the artificial propagation of the same species. Three basic stages were selected: seed, 15 week old juvenile seedlings with several (<7) leaves and semi-mature plants with fully developed root systems and many (>10) leaves. In the trials, seedlings were raised at the Victoria University Iramoo Indigenous Nursery using standard techniques known to be successful for these species under glasshouse and controlled field conditions. Transplantation to field conditions at Iramoo Wildlife Reserve occurred at the selected key life cycle stages listed above, which also corresponds to transplantation of seedlings used in standard glasshouse propagation methods.

Trials in the field investigated the interactions between two key treatments: (a) exclusion of invertebrate herbivory: mainly red-legged earth mites, millipedes, and ants (from field observation) and (b) soil disturbance. Factorial combinations of the above two variables were investigated.

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. Atrazine (as Nufarm nutrazine) herbicide was applied at a rate of 8.7kg per hectare 12 months prior and 4 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). Standard rate MCPA-dicamba was applied 8 weeks prior to planting to remove further germination 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. Lasting effects of herbicide treatment were not viewed as important as both degrade rapidly on contact with soil.



Photo 35

Author amongst Trial Plots, Iramoo Wildlife Reserve, St Albans

Individual treatment plots measured 0.5 x 1m rectangle (photo 35). For each treatment, there were eight replicates. Plots were randomly allocated within an overall grid pattern. Each plot contained three smaller plots to accommodate the three life stages to be trialled (semi-mature plants (30 weeks old), juvenile plants (15 weeks old) and ungerminated seed). Six semi-mature plants, 8 juvenile plants and 50 seeds were planted into the respective sub-plots.

All plants were planted in late winter/early spring (second week of August). Prior to planting, semi-mature plants and juvenile plants were grown in a shade house for 28 and 13 weeks respectively prior to hardening off for two weeks. The time of germination for semi-mature plants and juvenile plants was offset so that both types were planted out at the same time.

Exclosures constructed to exclude non-flying invertebrates consisted of 15 cm high aluminium flashing buried to a depth of 5 cm surrounding each exclusion treatment, with the top 5 cm coated with petroleum jelly (photo 35). Site

preparation in relation to invertebrates was based on advice from Risdill-Smith (C.S.I.R O., pers. comm.).

Soil disturbance was carried out to a depth of 5 cm using the pointed end of a small hand-held mattock. The depth of 5 cm was chosen to mimic the depth of disturbance created by small digging animals such as bandicoots and echidna (Pyrke 1993; Trigg 1996). No attempt was made to ensure an even soil texture although “large” soil clumps were broken up slightly. The soil surface was lightly levelled by hand to remove any large depressions or hillocks.

Germination and survival of transplanted plants was recorded weekly as presence or absence.

Data were tested for normality and subsequently square root transformed according to Zar (1999) to achieve a more normal population distribution before being statistically compared. A general linear model three-way Anova using Version 11 of SPSS was carried out.

4.0 Results

4.1 *In vitro* Germination

4.1.1 Total percentage germination

For all species for which germination took place, total percentage germination under light conditions was generally high, with three quarters of species having greater than 50% total percentage germination within the 34-day trial period (*Figure 1*). Mean percentage germination across all species was 64%. One species, *Microseris* sp.3 had a markedly lower germination (31%) under the temperature regime used in this trial. Germination of *Microseris* sp.3 was however, greatly improved under lower temperature regimes (data not included).

Three species, *Arthropodium strictum*, *Ranunculus lappaceus* and *Senecio cunninghammii* completely failed to germinate in either treatment. Upon closer inspection of *S. cunninghammii* it was revealed that the embryos were incompletely developed. The failed germination of *A. strictum* and *R. lappaceus* remains unexplained. These species are not included in the presented data.

Total percentage germination under total darkness varied widely from 0% to 97%. Two-thirds, or ten of the fifteen species that were tested, had greater than 50% total germination in darkness. Mean germination across all species was 54%. In just over one third of the species, germination was negatively affected by darkness and for 17% germination was positively affected by darkness (see later sections).

Light was a highly significant factor ($p < 0.001$) in the overall germination of *Brachyscome diversifolia* and *Microseris* sp. 3 (*Figure 1*). Both species germinated under light conditions but completely failed to germinate under total darkness.

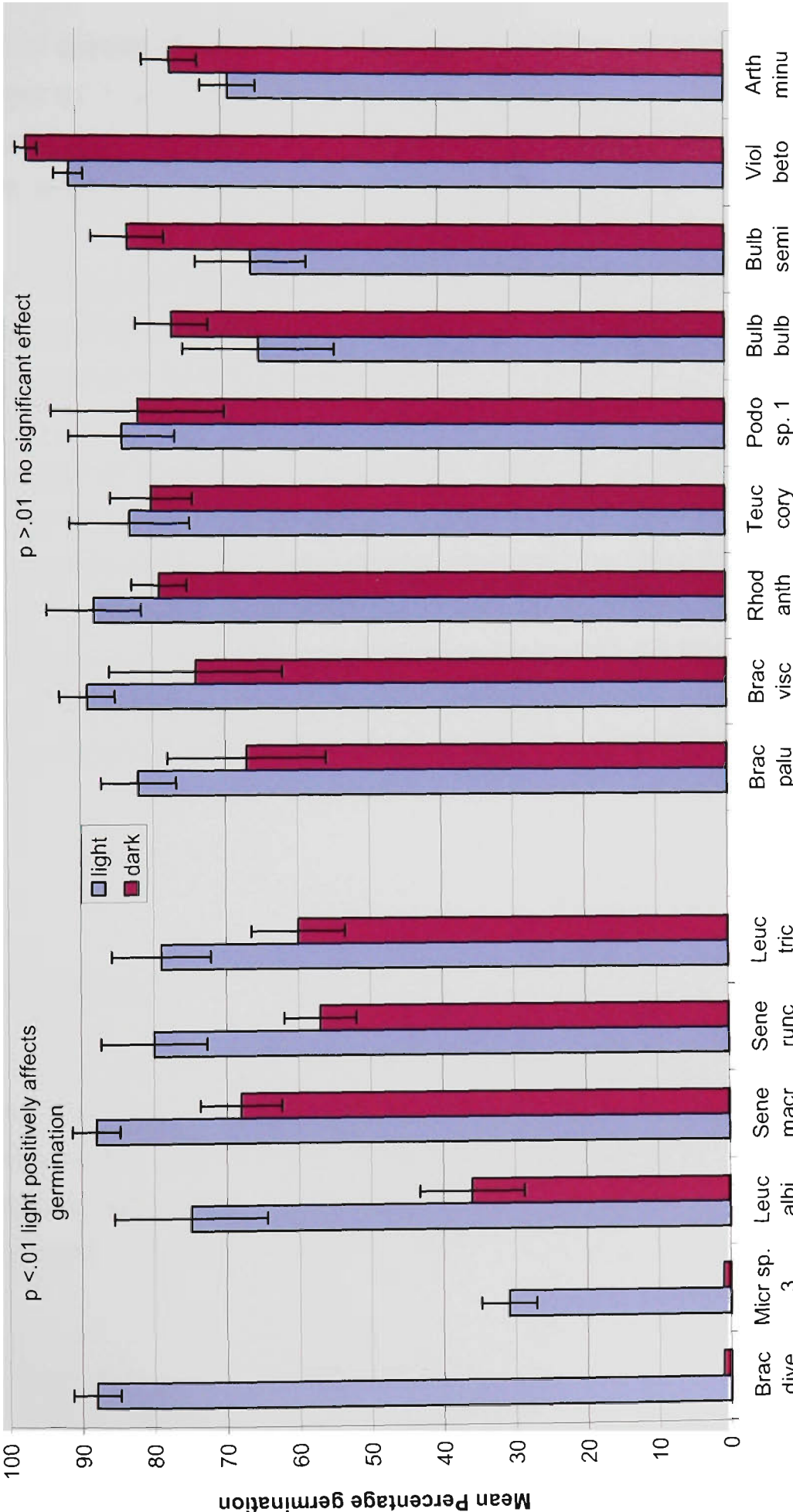
Light was also a significant ($p < 0.01$) factor affecting the overall germination of *Leucochrysum* spp. and *Senecio* spp. (Figure 1). These species showed greatly enhanced germination after exposure to light compared to the inhibition of germination observed when seeds were kept in total darkness.

A range of species, including *Bracteantha* spp, *Podolepis* sp. 1, *Rhodanthe anthemoides*, *Teucrium corymbosum*, *Arthropodium minus*, *Bulbine* spp and *Viola betonicitolia* showed no significant difference in their germination response to light or dark (Figure 1).

4.1.2 Lag Time

The effect of light and dark on the period from sowing to germination (**LAG** time) varied, from having no effect to having a highly significant effect (Figure 2). All species that germinated, with the exception of *Brachyscome diversifolia*, germinated rapidly (very fast to fast) under the preferred conditions for that species. *Brachyscome diversifolia* was the only species to have moderate germination speed overall (24 days). *Senecio macrocarpus* was sufficiently inhibited in germination speed under dark conditions to alter its germination characteristics from high to moderate speed (14-28 days) but as mean speed was only slowed by two days this did not appear to be statistically significant although variability between replicates was high. *Bulbine bulbosa* and *Arthropodium minus* were classified as having moderate germination speed under light conditions but were otherwise classified as fast and very fast respectively under dark conditions.

FIGURE 1 Effect of light or dark treatments on percentage germination in a range of forb species.



Species grouped according to response to light vs. dark

Error bars represent Standard Error of Mean

For *Teucrium corymbosum* and *Bulbine semibarbata* light and dark treatments had no significant effect on LAG time for these species (*Figure 2*)

The majority of species (72%) showed some effect of light or dark on LAG time. *Podolepis* sp. 1, *Leucochrysum albicans* ssp. *albicans* var. *albicans* and *Senecio macrocarpus* showed the least effect but this was still determined to be significant ($p < 0.01$).

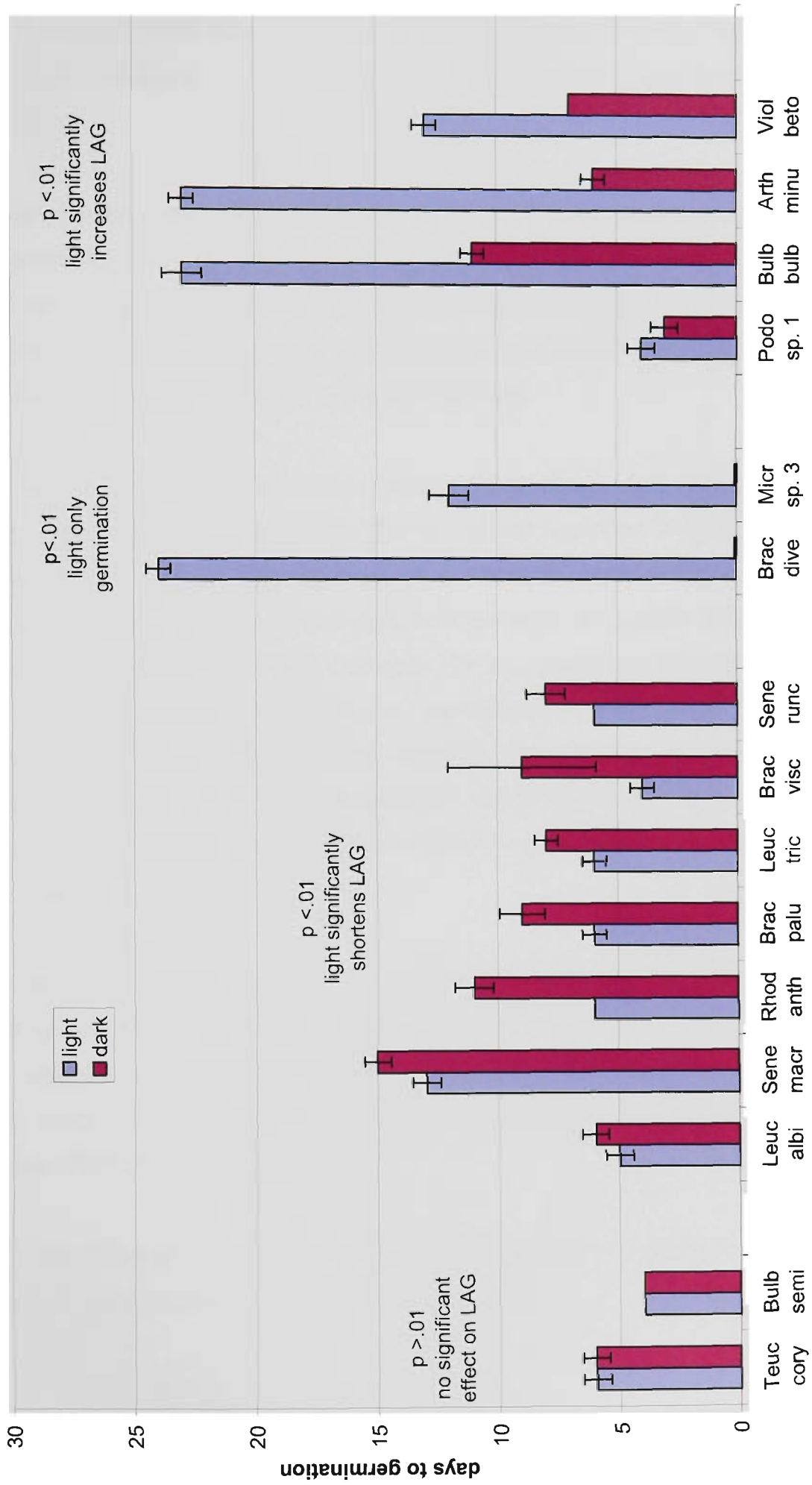
Exposure to light significantly decreased LAG time ($p < 0.001$) for *Rhodanthe anthemoides*, *Bracteantha palustris* and *Leucochrysum albicans* ssp. *albicans* var. *tricolor* compared to dark treatment (*Figure 2*).

Thirty-nine percent of all species showed a highly significant ($p < 0.001$) effect on LAG time after exposure to either light or total darkness. *Brachyscome diversifolia* and *Microseris* sp. 3 showed the most extreme response with complete lack of germination under total dark (*Figure 2*). *Bracteantha viscosa* and *Senecio runcinifolia* exhibited an extreme shortening of LAG time upon exposure to light. Conversely, *Bulbine bulbosa*, *Arthropodium minus* and *Viola betonicifolia* exhibited an extreme lengthening of LAG time upon exposure to light.

4.1.3 Germination speed

The effect of light and dark treatments on germination speed (t_{50} – the time from sowing until 50% of total germination) was significant ($p < 0.001$) for three-quarters of the species tested that germinated (*Figure 3*). For those species affected, light or dark treatment increased or decreased germination speed by between 3-18 days.

Figure 2 Effect of light and dark on LAG time before germination for a range of forb species.



Error bars represent Standard Error of Mean

Germination speeds under light conditions were classified as very fast (<7 days) to fast (<14 days) for 9 of the 15 species that germinated. The remaining 6 species were classified as having moderate germination speed (between 15 and 28 days). Overall, all species that germinated reached t_{50} in under 28 days.

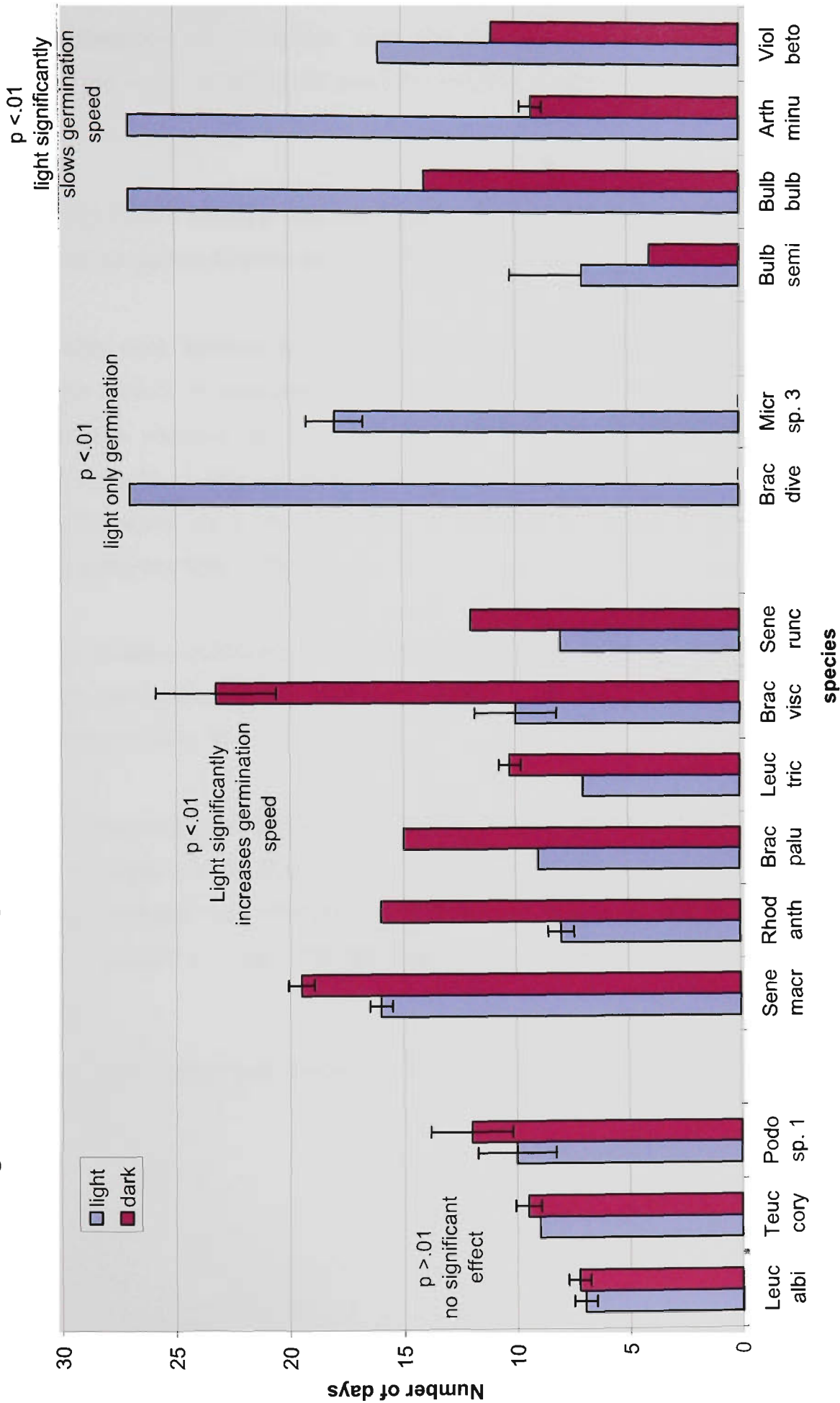
Germination speeds under dark conditions were slower for only five species, and increased for four species (*Figure 3*). *Brachyscome diversifolia* and *Microseris* sp.3 failed to germinate under total darkness. Overall, for those species that germinated in darkness, germination speed under total darkness was fairly rapid with t_{50} being reached in under 22 days.

For eight of the ten species of daisies (family Asteraceae) included in the study, germination increased in speed (time to t_{50}) with exposure to light, with this increase being significant ($p < 0.001$) for 6 of the 10 species (*Figure 3*). Two species of daisy, *Microseris* sp.3 and *Brachyscome diversifolia* failed to germinate under conditions of total darkness. Of the remaining two species that did not exhibit large increases in germination speed under light conditions, *Leucochrysum albicans* ssp. *albicans* var. *albicans* showed no significant response in relation to germination speed and *Podolepis* sp. 1 showed a minor but significant ($p < 0.01$) increase in germination speed upon exposure to light.

Three of the four lily species (family Asphodelaceae) tested showed a significant ($p < 0.01$) delay to germination upon exposure to light (*Figure 3*) with one species *Arthropodium strictum* failing to germinate under either treatment. *Viola betonicifolia* showed a significant ($p < 0.001$) delay of 5 days to t_{50} germination under light treatment.

Teucrium corymbosum showed no differential in response to either light or dark in relation to germination speed (*Figure 3*).

Figure 3 The effect of light or dark on germination speed (t_{50}) for a range of forb species.



Error bars represent Standard Error of Mean

4.1.4 Duration of emergence

The effect of light or dark treatments on the duration of emergence (the time from first emergence of a radical from the first germinating seed until completion of germination within the seed lot) varied between species (*Figure 4*).

For nine of the fifteen species that germinated, light had a highly significant ($p < 0.01$) effect on period of emergence (*Figure 4*).

Compared with dark treatments, exposure to light significantly ($p < 0.01$) shortened the period of emergence of *Bracteatha palustis* (shortened by 4 days) *Bracteatha viscosa* (by 11 days), *Bulbine bulbosa* (shortened by 11 days), *Podolepis* sp. 1 (by 10 days) *Rhodanthe anthemoides* (by 5 days), *Senecio macrocarpus* (by 3 days), *Senecio runcinifolius* (by 3 days) and *Viola betonicifolia* (shortened by 2 days).

One species *Bulbine semibarbata* showed significant ($p < 0.001$) extension of the period of emergence (by 12 days) with exposure to light compared with dark treatments (*Figure 4*).

Four species produced no significant contraction of the period of emergence in relation to exposure to light ($p > 0.01$). These included *Leucochrysum albicans* ssp. *albicans* var. *albicans* (2 days), *Leucochrysum albicans* ssp. *albicans* var. *tricolor* (1 day), *Arthropodium minus* (2 days) and *Teucrium corymbosum*.

Brachyscome diversifolia and *Microseris* sp. 3 only germinated under the light treatment.

Figure 4 Effect of light and dark on duration of emergence of radical from seed for a range of forb species.

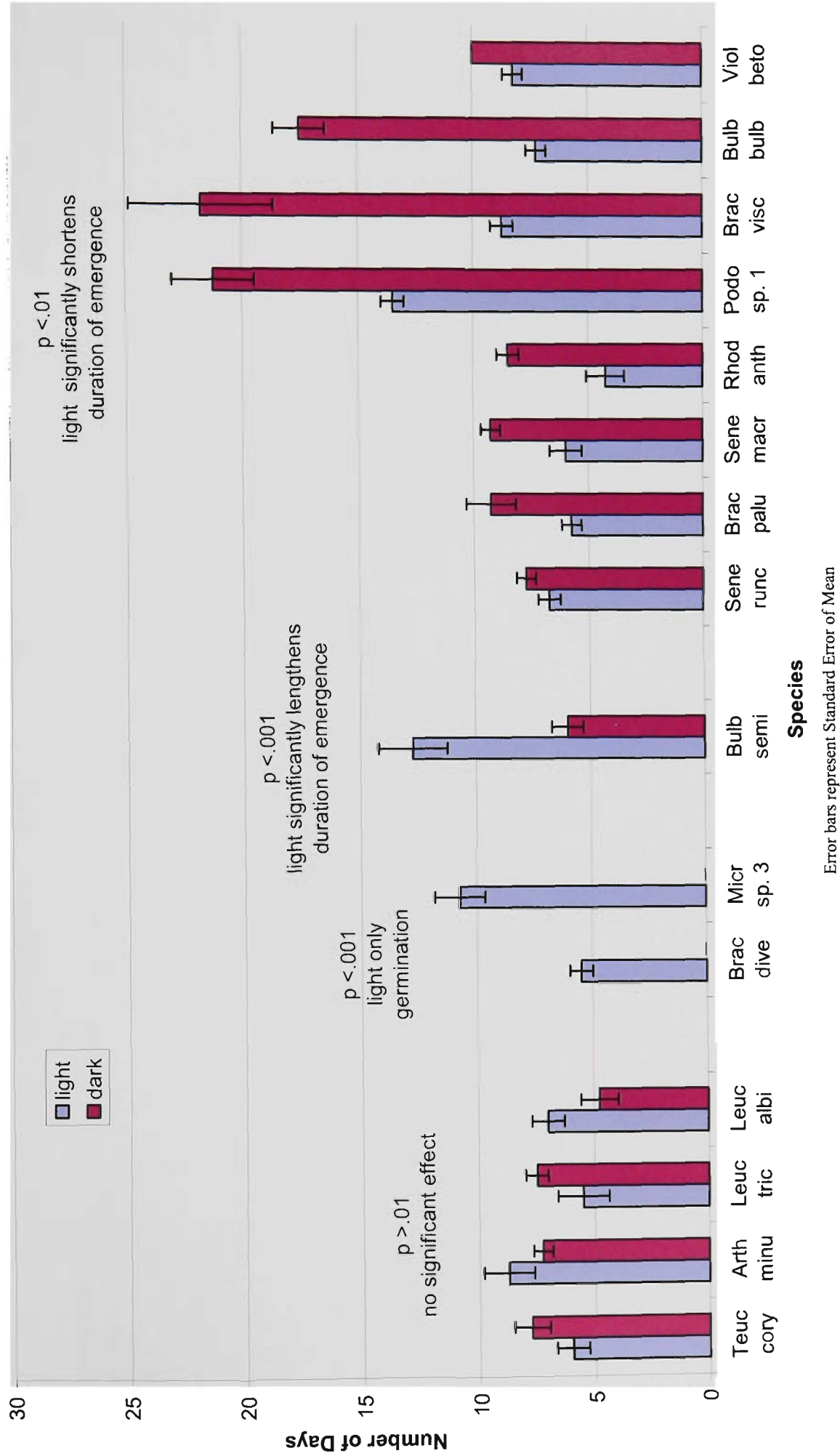


Table 2 Summary of significant effect of light on key germination characteristics in a range of forb species

	TOTAL GERMINATION	SHORTENS LAG	LENGTHENS LAG	SHORTENS T50	LENGTHENS T50	SHORTENS DURATION OF EMERGENCE	LENGTHENS DURATION OF EMERGENCE
<i>Arthropodium minus</i>			X		X		
<i>Brachyscome diversifolia</i>	X		X		X		X
<i>Bracteantha palustris</i>		X		X		X	
<i>Bracteantha viscosa</i>		X		X		X	
<i>Bulbine bulbosa</i>			X		X	X	
<i>Bulbine semibarbata</i>					X		X
<i>Leucochrysum albicans</i> ssp. <i>albicans</i>	X	X					
<i>Leucochrysum albicans</i> ssp. <i>tricolor</i>	X	X		X			
<i>Microseris</i> sp. 3	X		X		X		X
<i>Podolepis</i> sp. 1		X				X	
<i>Rhodanthe anthemoides</i>		X		X		X	
<i>Senecio macrocarpus</i>	X	X		X		X	
<i>Senecio runcinifolia</i>	X	X		X		X	
<i>Teucrium corymbosum</i>							
<i>Viola betonicifolia</i>			X		X	X	

4.2 *In vivo* recruitment and survival in field trials

4.2.1 *Recruitment and survival for Podolepis* sp. 1

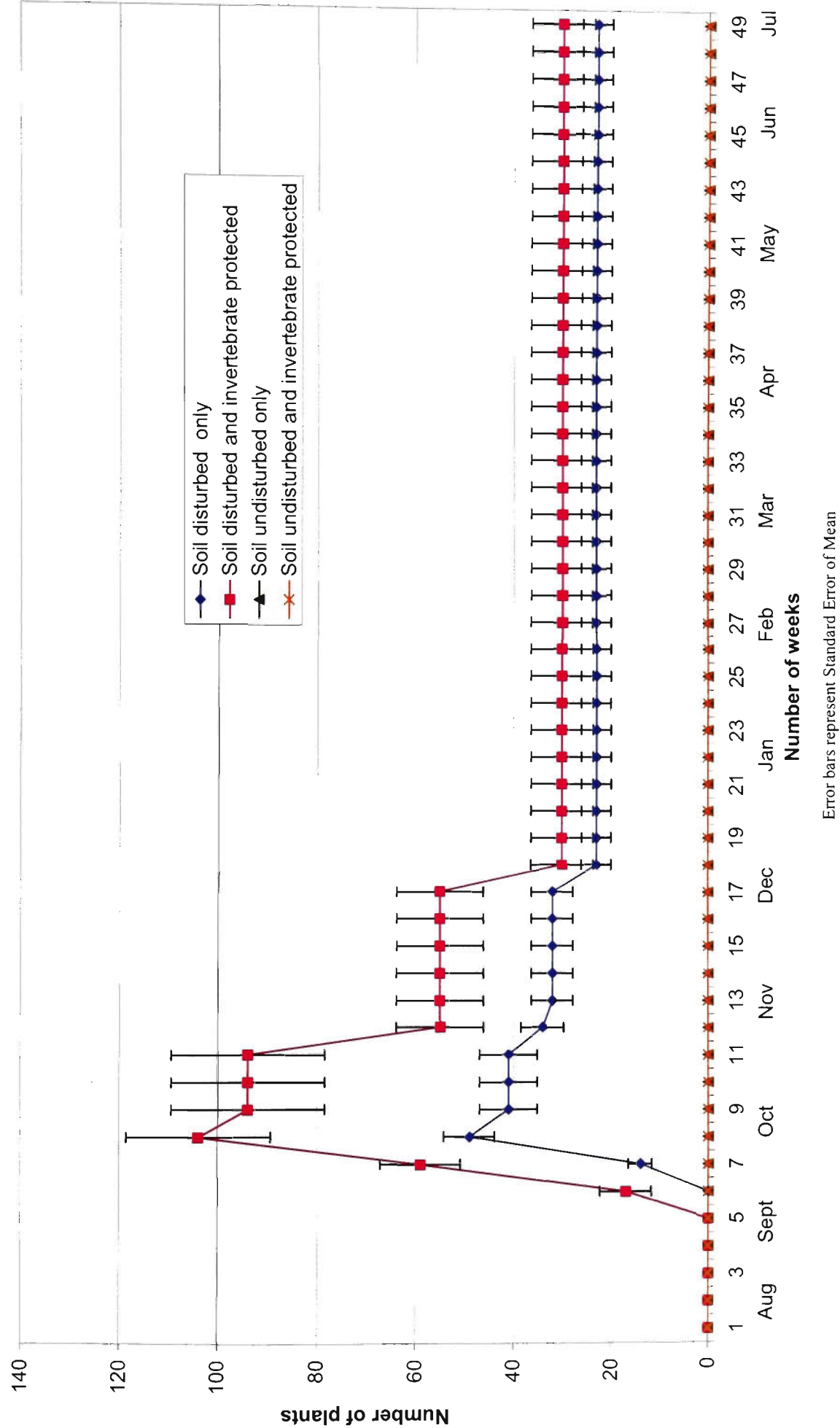
4.2.1.1 Recruitment from seed and subsequent survival of seedlings

Recruitment of *Podolepis* sp. 1 plants from seed occurred only in soil-disturbed plots (*Figure 5*). 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 7 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 unprotected plots and 28% on protected plots (*Figure 5*). 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 (*Figure 5*).

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 ($p > 0.1$).

Figure 5 Germination from seed and subsequent survival of *Podolepis* sp. 1 over 50 weeks (n=8)



Differences in survival rates between treatments for transplanted juvenile *Podolepis* sp. 1 plants were marked, with overall survival ranging from 10% to 82% (*Figure 6*). Survival was highest on soil-disturbed plots with 82% survival on invertebrate-protected sites and 71% on unprotected sites. Juveniles planted into undisturbed soils showed high mortality rates with overall survival of 14% on invertebrate-unprotected plots and 10% on protected sites.

Survival of juvenile plants in soil-disturbed treatments was significant ($p < 0.001$) compared to undisturbed plots. There was also a trend to higher survival on unprotected plots compared with protected plots, the reverse of the seed plots, but the differences were not statistically significant ($p > 0.01$).

4.2.1.3 Survival of semi-mature plants

Variation in survival between treatments was least marked in transplanted semi-mature plants with overall survival across all treatments ranging from 66% to 89% after 50 weeks. Neither soil disturbance nor protection from invertebrates showed statistically significant differences from their respective controls even though there was a slightly higher average survival rate on soil-disturbed and protected sites (*Figure 7*).

4.2.1.4 Comparison of survival between treatments

A comparison of the survival of the various life stages to treatment type can be found in *Figure 8*. It is clearly demonstrated that treatment type had limited impact on survival of semi-mature plants but soil disturbance is critical to survival of juvenile plants and plants germinated in the field from seed. Invertebrate protection provided limited but significantly improved survival for juvenile and semi-mature plants but an inhibitory effect on plants germinated in the field from seed.

Figure 6 Survival of juvenile plants of *Podolepis* sp. 1 over 50 weeks (n=8)

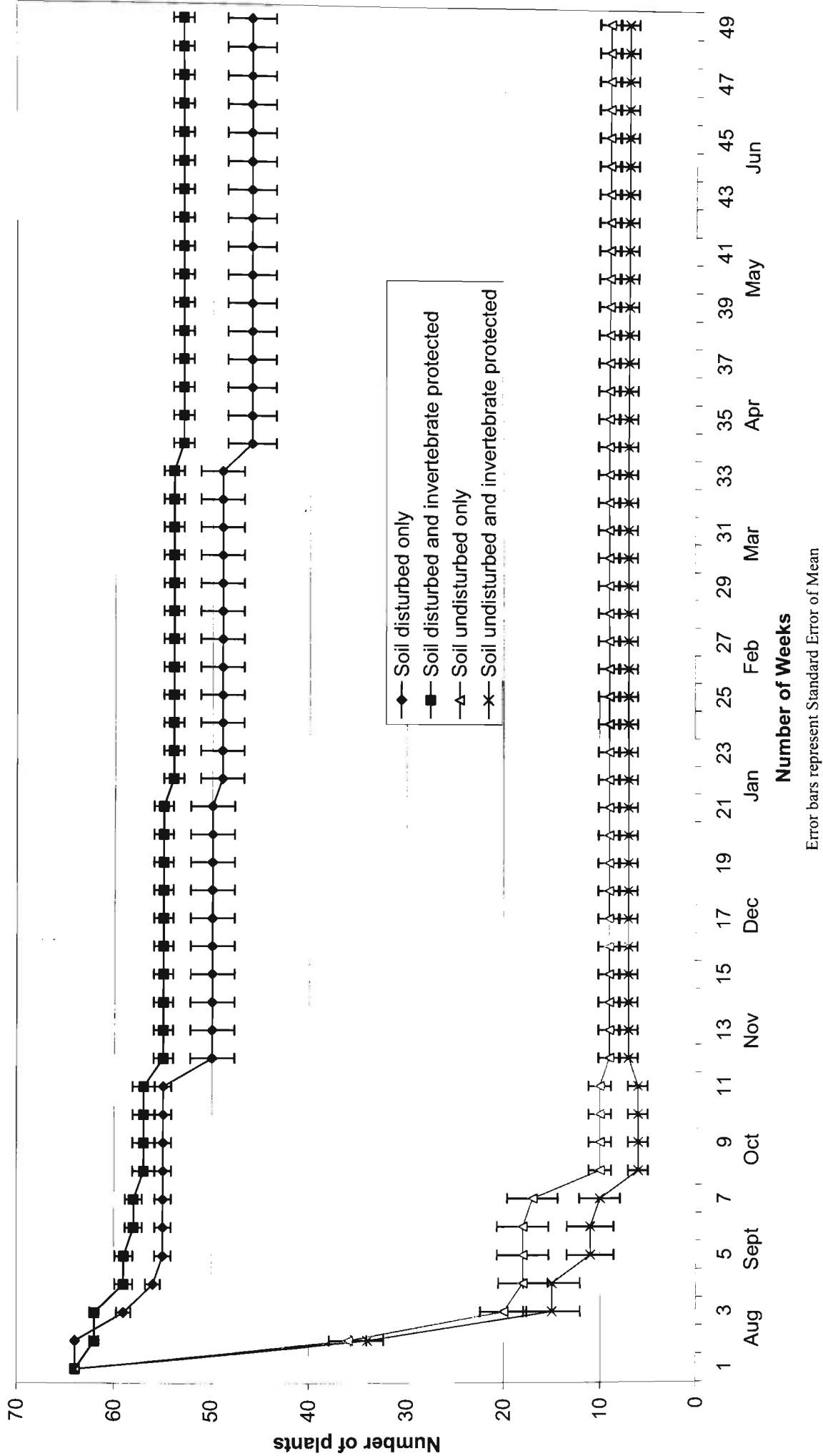


Figure 7 Survival of Semi-mature plants of *Podolepis* sp. 1 over 50 weeks (n=8)

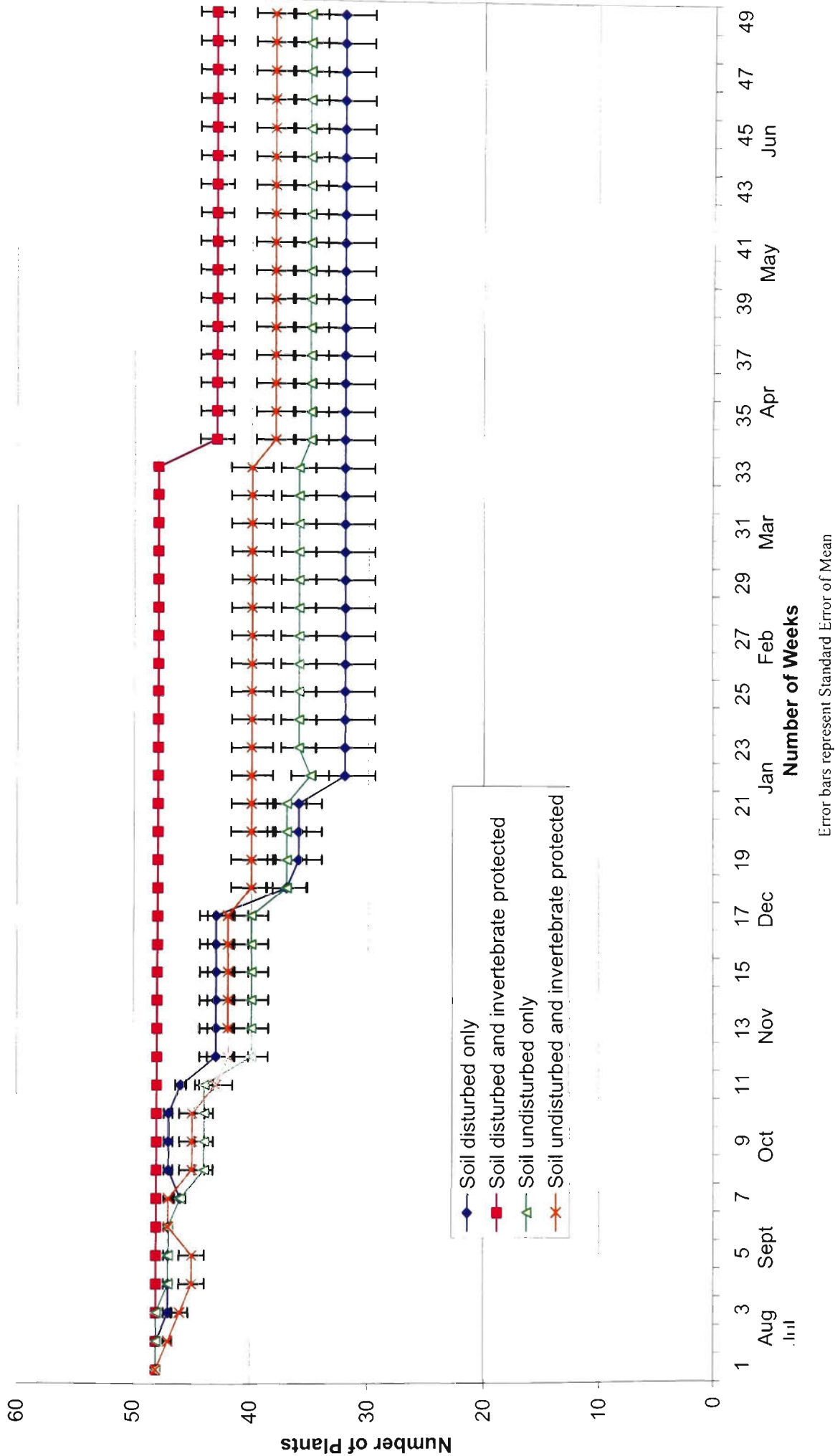
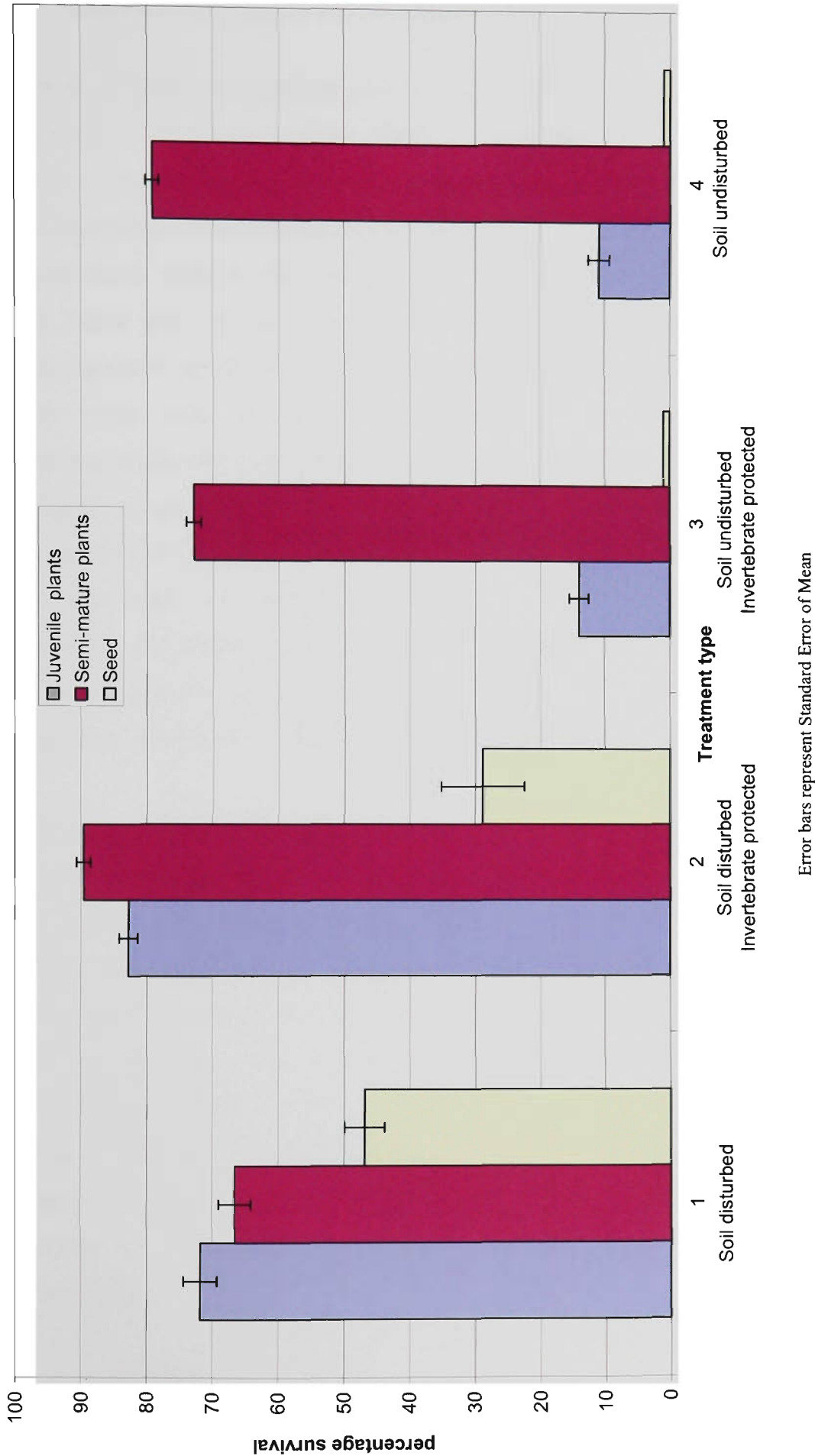


Figure 8 Comparison of survivability between plant type and treatment type for *Podolepis* sp. 1 after 50 weeks (n=8).



4.2.2 Recruitment and survival for *Bulbine semibarbata* (Perennial form)

4.2.2.1 Recruitment from seed and subsequent survival of seedlings

Recruitment of *Bulbine semibarbata* plants from seed occurred on both types of soil disturbed treatment plots; that is invertebrate protected and unprotected treatments (Figure 9). There was also recruitment from seed, but at lower numbers than on invertebrate protected plots on undisturbed soil. 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 9). 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 9). 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 plots; 10% on soil-disturbed only plots and 0% on soil-undisturbed plots and invertebrate protected plots (Figures 9 and 12).

Recruitment from seed was found to be significantly higher ($p<.001$) 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.

4.2.2.2 Survival of juvenile plants

There were marked differences between treatments for survival of transplanted juvenile *Bulbine semibarbata* plants, with overall survival ranging from 32% to 68% (Figure 10). Survival was highest on disturbed soil plots (68%) with no difference in survival between invertebrate protected and unprotected plots. Juveniles on undisturbed soils showed a mortality rate of 100% after 17 weeks. There was a trend to higher survival on invertebrate protected plots (58% survival after 50 weeks) compared with unprotected plots (32% survival) but this was not shown to be statistically significant.

The higher survival rates on soil-disturbed than on undisturbed plots was statistically significant ($p<0.0001$). Protection from invertebrates was not significant overall ($p=0.390$) and although apparent survival percentages were lower on undisturbed soils this did not prove to be statistically significant ($p=0.152$).

4.2.2.3 Survival of semi-mature plants

Differences in survival between treatments were least marked in semi-mature plants with overall survival across all treatments ranging from 52% to 77% after 50 weeks (Figure 11). Neither soil disturbance nor protection from invertebrates resulted in statistically significant differences ($p>0.05$) in survival between treatments even though there were slightly higher average survival rates on invertebrate protected plots.

A comparison of the survival of the various life stages to treatment type can be found in Figure 12. It is clearly demonstrated that treatment type had limited impact on survival of juvenile and semi-mature plants but soil disturbance is critical to survival of plants germinated in the field from seed. Invertebrate protection provided limited improved survival for juvenile and semi-mature plants but greater effect on plants germinated in the field from seed.

Figure 9 Germination from seed and subsequent survival of *Bulbine semibarbata* (perennial form) over 50 weeks (n=8)

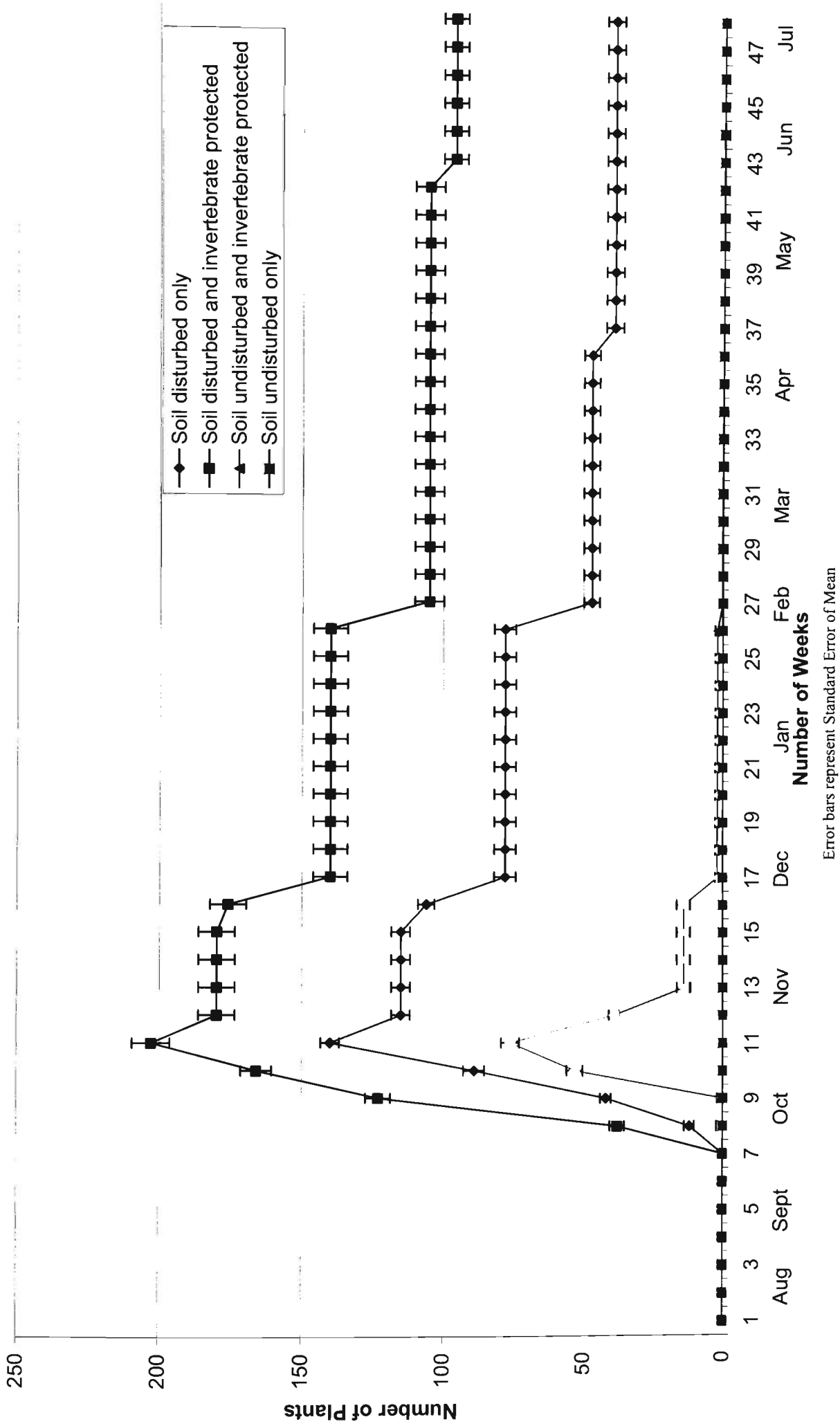


Figure 10 Survival of Juvenile plants of *Bulbine semibarbata* (perennial form) over 50 weeks (n=8)

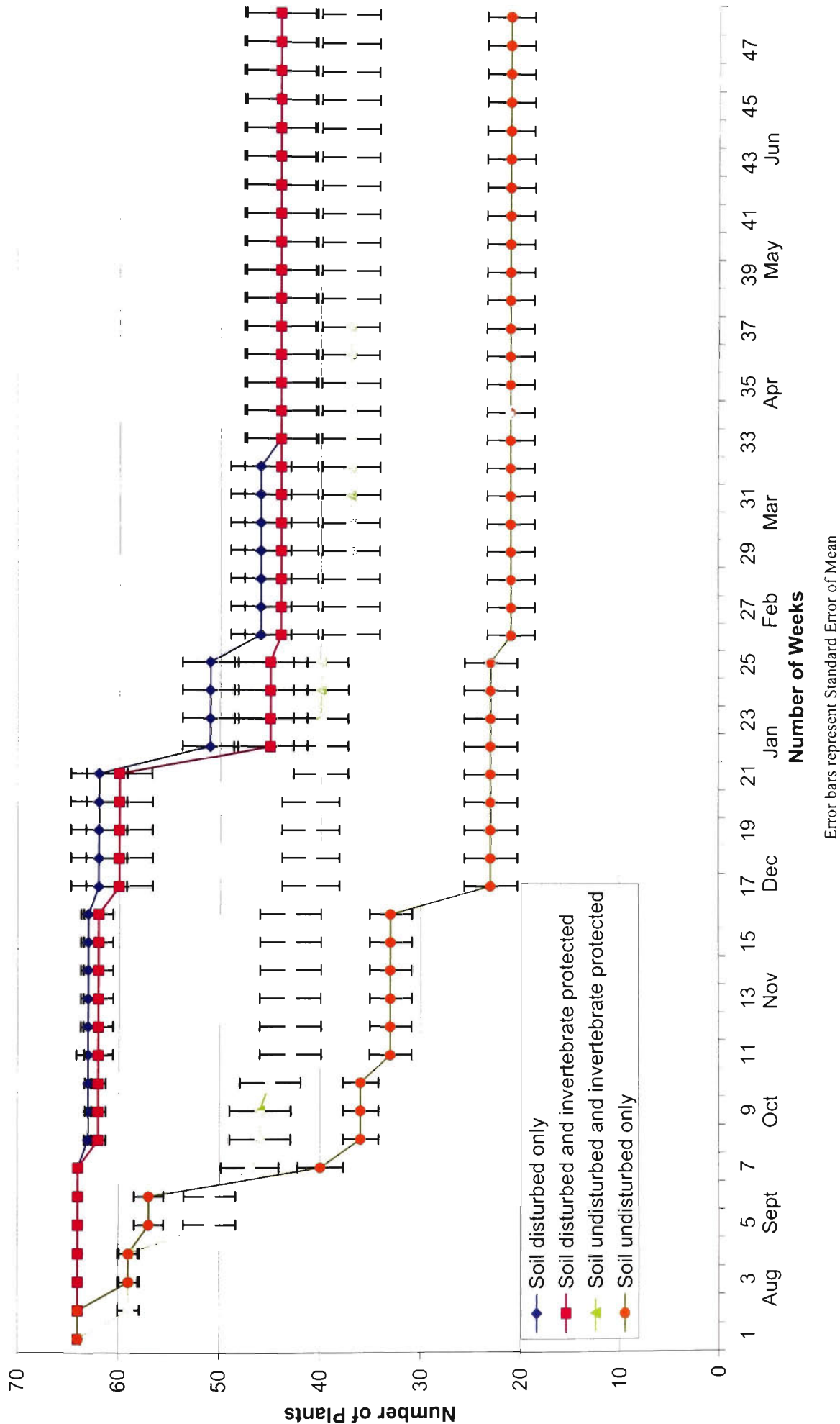


Figure 11 Survival of Semi-mature plants of *Bulbine semibarbata* (perennial form) over 50 weeks (n=8)

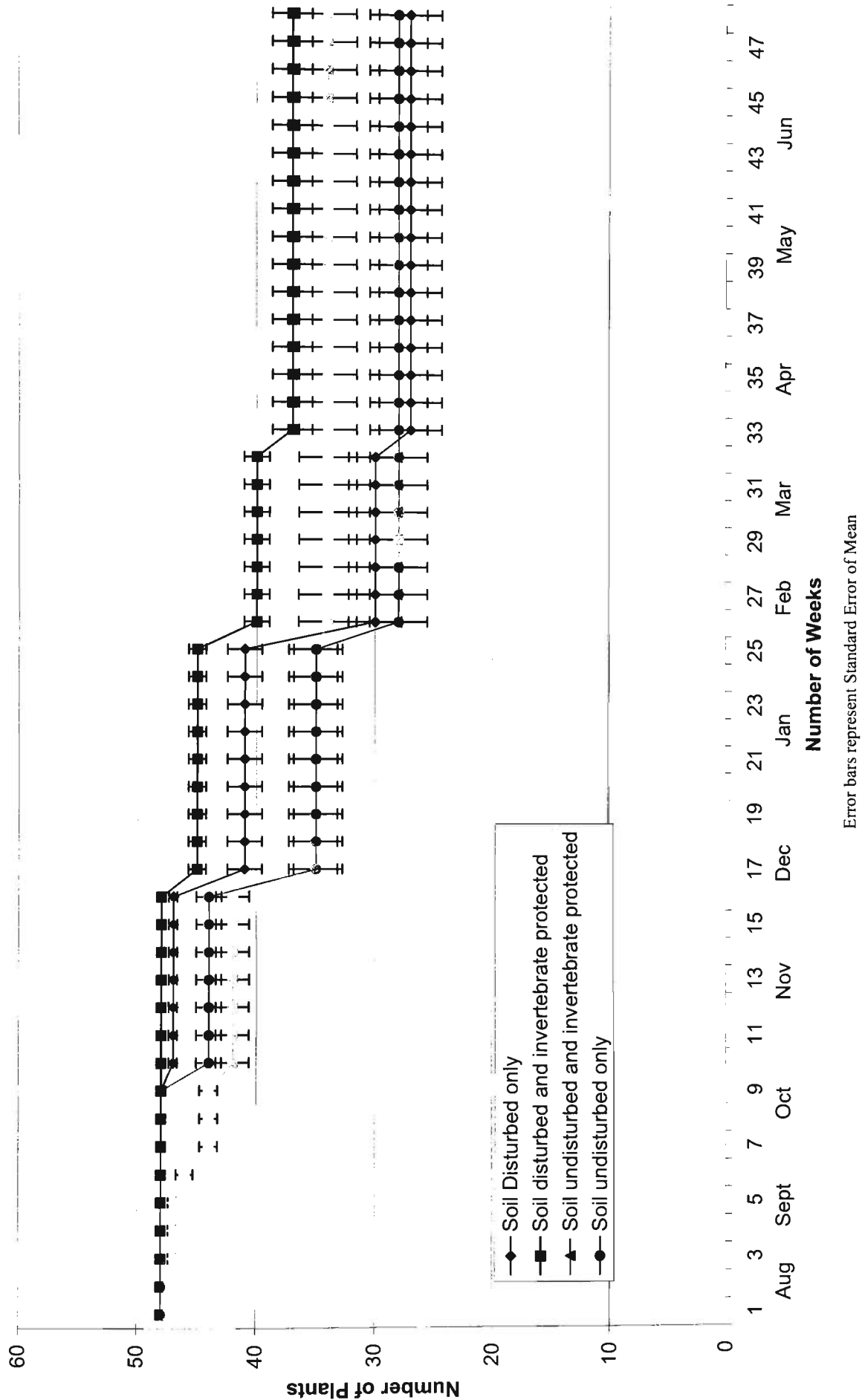
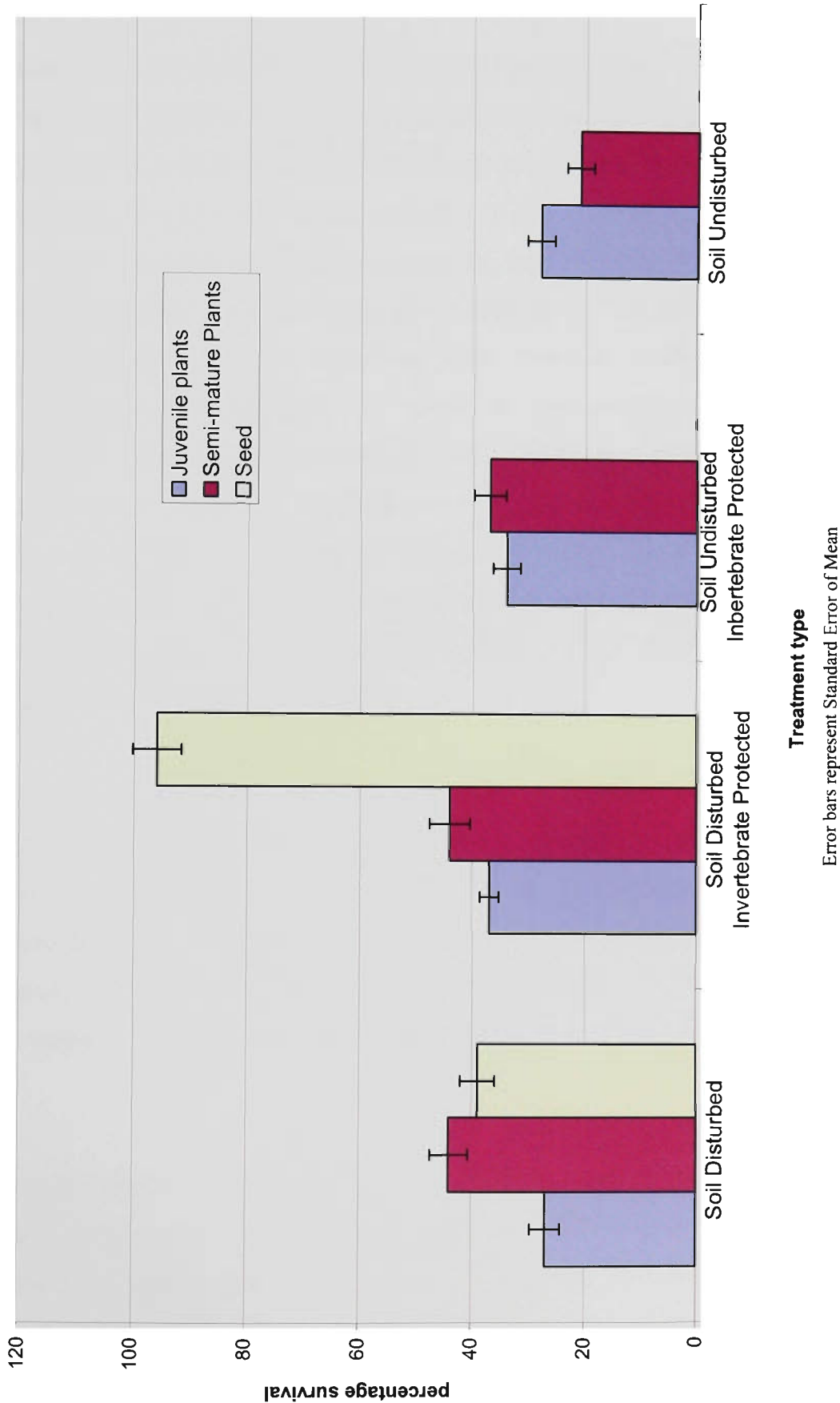


Figure 12 Comparison of survivability between plant type and treatment type for *Bulbine semibarbata* (perennial form) after 50 weeks (n=8)



4.2.3 *Episodic death in Podolepis sp. 1 and Bulbine semibarbata*

Differences in overall survival masked finer scale variations between life stage and treatment type. Attrition was not linear but punctuated and closely correlated to heat and moisture stress experienced under field conditions (no data available).

For *Podolepis* sp. 1 death of semi-mature plants occurred in a series of steps in the first 22 weeks (August to January) of the trial with another step at week 33 (April) (Figure 7). For *Bulbine semibarbata* there was a more regular series of steps in mortality (Figure 11). Little variation in the episodic pattern of mortality was noted between invertebrate protected and unprotected plots on undisturbed soils for either species. There was a difference in survival pattern observed in *Podolepis* sp. 1 on disturbed soils between protected and unprotected treatments. Specifically, no death of semi-mature plants of *Podolepis* sp. 1 was noted on the soil-disturbed plots until week 33 (Figure 7). Death of semi-mature plants of *Podolepis* sp. 1 on plots that received disturbance but no protection closely paralleled the pattern of mortality in undisturbed unprotected treatments but had the highest rate of death overall. Overall, the combined and interactive effects between soil disturbance and invertebrate protection were not significant.

Punctuated death, possibly related to heat and moisture stress, was noted in juvenile plants in soil-disturbed plots but was notably more pronounced in the first 12 weeks for *Podolepis* sp. 1 (Figure 6). There was relative stability in survival of *Podolepis* sp. 1 for the remainder of the study period. Punctuated death was also noted in juveniles of *Bulbine semibarbata* but this did not happen until week 21 (Figure 10) with relative stability in numbers after that point.

Death of juvenile plants of *Podolepis* sp. 1 on undisturbed soil was rapid with 85% on invertebrate unprotected sites and 89% on protected sites within 12 weeks (Figure 6). Juvenile plant mortality of *Podolepis* sp. 1 on soil disturbed plots closely paralleled semi-mature plant mortality, with a series of smaller

steps over a 33-week period. Death of juvenile plants of *Bulbine semibarbata* closely mimicked that of *Podolepis* sp. 1 but was not as marked with mortality rates of 34% on protected plots and 64% on unprotected plots after 17 weeks (Figure 10).

All plants, regardless of treatment attained a similar size by the end of the trial. On average, each clump of *Podolepis* sp. 1 contained 3 rosettes and a total of 27 leaves. *Bulbine semibarbata* clumps averaged 3 rosettes and 17 leaves. Flowering was greatly reduced on undisturbed plots in both species. Of all surviving plants of *Podolepis* sp 1 on undisturbed soil, only one flowered. Conversely most surviving plants on disturbed soils flowered. The differences were less marked on *Bulbine semibarbata* with most plants flowering irregardless of treatment. Numbers of flowers per inflorescence was however reduced on undisturbed plots.

5.0 Discussion

5.1 Overall germination percentages

For the majority of the species utilised in this study the germination percentages were high in response to the single temperature regime used. Overall germination percentages measured in this study are consistent with the results of germination tests carried out on other grassy ecosystem forbs (McIntyre 1990, Morgan and Lunt 1994, Morgan 1998 and Clarke *et al.* 2000).

Only very small differences in overall total germination rates were noted between this study and other studies on grassy ecosystem forb species. For example Morgan (1998) found that for *Podolepis* sp. 1 percentage germination was 75% compared to the 81% found in this study. This small percentage of variation is to be expected between different seed lots and source populations and falls within the standard germination tolerances of 7-8% set for similar tests by the Association of Official Seed Analysts (1970). Similar degrees of variation have been found in studies carried out by the Melbourne Indigenous Seed Bank of the species used in this study and other plant species (unpublished data).

5.2 Responses to light or dark

There were some clear groupings in the response of the various species to light or dark treatment in relation to overall percentage germination. As found in other studies (Willis and Groves 1991; Morgan 1998; and Clarke *et al.* 2000) there is a general tendency for members of the daisy family (Asteraceae) to respond positively to light. Seven of the ten species of daisy examined in this study exhibited a significant ($p < .01$) response to light in relation to overall germination indicators. However, when this potential trend was extended to LAG time, germination speed (t_{50}) and duration of emergence this pattern became inconsistent between and within species.

The responses of *Brachyscome diversifolia* and *Microseris* sp 3 to light were the most marked with no germination at all under total darkness. Both of these species occur most abundantly in habitats that have little competing vegetation cover or high underlying levels of disturbance indicating that they may be inhibited by dense overstorey vegetation cover

There was a small group of species that exhibited a negative response to light. Notable amongst these were the lilies *Arthropodium* and *Bulbine*, and the Native Violet, *Viola betonicifolia*. Previous studies by Morgan and Lunt (1999) indicate that at least some of the native lilies may have a secondary trigger of low temperature. Hitchmough *et al.* (1996) indicated that light in the form of canopy gaps was necessary for successful recruitment of *Bulbine bulbosa*. Experience with North American and European Liliaceae would indicate that it is common for the lilies to exhibit a need for lower temperatures and darkness to stimulate germination (Mathew 1978). It is common practice in south-eastern and south-western Australia to sow Lilies in autumn or very early spring to avoid the inhibition of germination created by higher temperatures (Ralph 1997).

The lilies of lowland grassy ecosystems would appear to be autumn germinating geophytes that avoid moisture stress by growing during the period of highest humidity and lowest evaporation rates that occur in winter (personal observation). Exposure to light may be correlated with increased temperature and lower humidity levels and therefore light might be an appropriate trigger to discourage germination. *Viola* species worldwide are known for their occupation of mesic habitats and most species are known to have increased germination under conditions of darkness (Bruce, 1976).

The results for several species of forbs in response to light and dark treatments are notable in that they differ from results found in other studies. One of the daisy species used in this study, *Podolepis* sp. 1, had no significant response to light in this study but did exhibit a strong and significant response in studies by Morgan (1998), and Clarke *et al.* (2000).

Arthropodium strictum failed to germinate in this study but had greater than 80% germination when trialled by Morgan (1998). The response of *Bulbine bulbosa* contradicted the results found in other studies (Morgan 1998, Clarke *et al.* 2000).

The reason for the discrepancy in *Podolepis* may be related to the taxonomy of the group of taxa formerly known as *Podolepis jaceoides* sens. lat. The taxa used for this study and by Morgan (1998) are known (Morgan pers.comm.) to be the same taxon, *Podolepis* sp. 1 (sensu Ross 2000) although it was classified as *Podolepis* sp. aff. *jaceoides* by Morgan (1998). As this plant is at present only known from populations on the basalt plains in southern Victoria it is highly unlikely that the plants used in the study by Clarke *et al.* (2000) from northern New South Wales, are taxonomically the same. The differences in response of the seed of Basalt *Podolepis* between this study and Morgan (1998) are unknown and may relate to the age of the seed, genotype, or any of a range of environmental and pre- and post-harvest conditions. Studies on other species (Lunt 1995) would indicate there could be a high degree of variation between different provenances.

Morgan (1998) and others (Willis and Groves 1991, Morgan and Lunt 1999) noted failure to germinate in the super-family Liliaceae, and temperature related germination in *Bulbine*. This may help to explain the contradictory results for *Bulbine* found between this study and those of Morgan (1998) and Clarke *et al.* (2000). As is found in *Podolepis* and several other grassland forb species, genetic and taxonomic differences in Liliaceae have not been fully elucidated. Lack of taxonomic clarity may also obscure some of the less obvious ecological responses to environmental stimuli for other species tested. For example, strong ecological and habitat preferences, and differences in response to light, dark, heat and cold, exist within the taxa that make up *Microseris scapigera* spp. agg. There are indications that similar taxonomic and ecological differences and possibly distinct taxa may exist within other "species" we presently classify as a single species. Examples include the current taxa *Bulbine bulbosa*, *Bulbine semibarbata*, *Dianella revoluta*, *Stackhousia monogyna*, etc. In addition to the above factors,

variations in response to stimuli such as light or darkness could also be attributed to localised physiologically tempered differences between populations.

Germination of grassy ecosystem species in this and other studies (McIntyre 1990, Morgan and Lunt 1994, Morgan 1998 and Clarke *et al.* 2000) strongly suggests that the total germination rates, for the majority of species, are positively influence by exposure to light, or that there is a neutral effect. A small proportion of species were found to be negatively influenced by light.

Although there were individual discrepancies in responses between studies on grassy ecosystem forb species, few species have been identified that have highly specialised germination requirements. Members of the Fabaceae (Pea flowers) and Ranunculaceae (Buttercups) have been shown to have specific requirements, notably scarification of hard seed coats in Fabaceae and leaching of chemical inhibitors in Ranunculaceae as reported by Ralph (1997). In both Fabaceae and Ranunculaceae light or dark has not been shown to have either a positive or negative effect on germination.

A major implication of the need for light by a range of grassy-ecosystem forb species is that disturbance to standing above-ground vegetation may be needed to stimulate germination. Removal of above ground vegetation would be consistent with the suggestions of Hitchmough (1996) and Clarke *et al.* (2000) in relation to the light requirements for germination of a range of life forms in grassy ecosystems. It is difficult to distinguish between exposure of seed to light to increase germination capacity (Delpratt pers comm.) and the requirements of canopy gaps to allow successful recruitment and establishment (Hitchmough 1996)

The removal of above-ground vegetation competition has been shown to be a contributing factor to recruitment and overall vegetation dynamics in tallgrass prairie vegetation in North America (Gibson 1989; Gibson *et al.* 1993; Freeman 1998) where grazing, fire and or drought coupled with trampling or digging removes competing above-ground vegetation, exposes seed and allows recruitment of a range of native species.

In lowland grassy ecosystems, maintenance of above-ground biomass has a rapid (eg. 3-5 year) detrimental effect on survival of mature plants of many forb species (Henderson and Hocking 1998), strongly suggesting that these forb species evolved and are adapted to vegetation with low levels of grass cover or could have adapted to disturbance regimes that are not consistent with present conditions.

Clarke *et al.* (2000) suggests that many growth forms of Australian native plant species respond to gaps created by disturbance and that germination takes place at the soil-surface. Canopy gaps were shown to be important for the recruitment of several native forb species by Morgan (1998b) with subsequent survival dependant on large canopy gaps (>100 cm). Although there are many processes associated with canopy gap formation the reduction of above-ground competition and increases in light penetration are particularly notable.

There is no reason to assume that native forb species are different from introduced forb species in their ecological responses to light or soil disturbance at least at the generic level. Many of the genera involved in this and closely related studies in Australia are represented in the grassy ecosystems of other countries, (e.g. *Teucrium*, *Viola*, *Senecio*, *Eryngium* and *Microseris* in the grassy ecosystems of North America). While individual species within each of these genera may have slightly different requirements, the majority of the species do not have specific germination requirements that differ greatly from the norm for the genus (The Seed Site 2003). Indeed, many species in these common and widespread genera are known to germinate freely under field conditions with some being well known "weeds" within their area of origin and elsewhere (Randall 2002). A small unpublished trial by the author on the native *Eryngium ovinum* shows that it has the same idiosyncratic needs as other *Eryngium* species from North America and Europe, namely a warm wet/ cold damp stratification.

It would appear that light alone is not the sole limiting factor in the recruitment of native forbs in grassy ecosystems. If this were the case, present levels of disturbance in the form of fire or grazing from both native and introduced animals would provide sufficient opportunity for recruitment of many native forb species on those sites with these types of disturbance. Morgan (2001), for example, demonstrated that recruitment of native forbs was slight over a period of four years in lowland grassy ecosystems with fire regimes ranging from annual to very infrequent. Henderson (2002) demonstrated a similar lack of recruitment over three years at four sites for several forb species in grassland remnants subjected to a range of burning and slashing regimes.

5.3 Responses to disturbance and removal of invertebrate herbivory

Successful germination and establishment from seed under conditions reported in this thesis of *Podolepis* sp. 1 and *Bulbine semibarbata*, in significant numbers demonstrates an ability for these species to recruit under field conditions. Germination and establishment of *Podolepis* sp. 1 and *Bulbine semibarbata* was however, clearly found to be predicated on the provision of suitable microsite conditions, primarily shallow soil disturbance.

Disturbance within lowland grassland is generally viewed as being detrimental to species composition in 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 “minimise soil disturbance” (Barlow 1998) with this mindset driving much environmental management work. This 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.

Lack of small-scale soil disturbance may help to explain the decline and rarity of many of the lowland grassy ecosystem forb species except in sites of very high quality or integrity. Landscape scale and localised extinction of many of the small mammals that once would have provided small-scale soil disturbance may account for the lack of seedling recruitment in many long-lived forbs (Lunt *et al.* 1998) but no studies have been carried out to demonstrate this. Large-scale weed invasion where such soil disturbance occurs may also contribute to lack of recruitment.

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.

The 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 eg. (*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 this 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 specialised means to “drill” seed into the soil, a characteristic exhibited by some members of the Poaceae (*Themeda*, *Austrostipa*, *Austrodanthonia*) and Geraniaceae (*Pelargonium*, *Erodium*). Unspecialised 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 but the effect would presumably been small as they were only 5-7cm tall. 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.

In this study, both *Podolepis* sp. 1 and *Bulbine semibarbata* produced large quantities of germinable seed and the germination requirements were not specialised.

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 (unpublished data) carried out on trial plots adjacent to the study site (within 10m) 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 7,000 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.

The creation of suitable microsites for the recruitment of native forbs in lowland grassy ecosystems is complicated by the presence of introduced species that may or may not have similar germination and recruitment requirements. Further study will need to be carried out to elucidate the conditions which promote or inhibit the comparative germination and survival of both native and introduced forb species.

The usefulness of soil disturbance in the field of restoration of grassy ecosystems is not generally recognised. The use of techniques such as those used in this study indicate that thorough site preparation including creating appropriate soil conditions is significant not only to germination but to survival of juvenile and semi-adult plants.

6.0 Conclusion

In keeping with past studies, this study shows that the germination response of forb species in lowland grassy ecosystems is variable. Seed of many lowland grassy ecosystem species germinate quickly and the overall germination rate is high. Light appears to be generally beneficial or neutral in its effect on the germination of most species, especially daisies. Darkness is beneficial to a few species, notably lilies and violets. Several species germination requirements were not determined in this study. Past and current investigation of the germination requirements of particular species may be hampered by lack of taxonomic clarity and variability in the responses of distinct populations.

This study contributes specific useful germination data on a range of poorly studied species. The information gained on these species may prove useful in the management of a range of ecosystems as many of these species are not confined to or primarily found in lowland grassy ecosystems.

It is possible to get high levels of germination, recruitment and survival of *Podolepis* sp. 1 and *Bulbine semibarbata* in the field, provided microsite conditions are met. Small-scale disturbance was a precondition for the successful germination and survival of both *Podolepis* sp. 1 and *Bulbine semibarbata*. Transplantation of semi-mature plants into field conditions was generally successful regardless of soil structure conditions. Successful transplantation and survival of juvenile plants was highly dependant on having a disturbed soil surface structure.

Herbivory did play a role in recruitment or survival of *Podolepis* sp. 1 and *Bulbine semibarbata* but was not as significant as disturbance. . Further studies are needed to clarify the role of invertebrates in recruitment of forbs.

This study clarifies that small-scale disturbance is needed for the successful germination and recruitment of *Podolepis* sp. 1 and *Bulbine semibarbata* in restoration works. Theories regarding small-scale animal disturbance or the

creation of canopy gaps through grazing and/or fire may be key factors in promoting recruitment of a range of forb species in grassy ecosystems in South-eastern Australia.

Although not directly studied, soil seed bank depletion and thorough site preparation may have played a direct role in the success or failure of recruitment through the removal of competing invertebrates, plants and seed, especially weed seed.

The findings of this study are directly applicable to the re-establishment of *Podolepis* sp 1, *Bulbine semibarbata* and similar forb species in lowland grassy ecosystems in South-eastern Australia. The importance of creating the correct microsite conditions would appear to be critical to the recruitment and maintenance of these species. The potential negative effects of disturbance, including weed recruitment, will need to be dealt with before successful recruitment and establishment of *Podolepis* sp 1 and *Bulbine semibarbata* can take place on a larger scale.

The results of this study are directly applicable to the practice of re-establishment of at least some native forb species in grassy ecosystems. The results of this study would imply a need for a radical departure from the present practice of minimal soil disturbance, use of semi-mature plants and mulching. Thorough site preparation including weed control, soil seed bank depletion and specific soil disturbance are seen as important contributing factors to the success of establishment of the species used in this study.

The problems of how to achieve recruitment and survival of native grassland forbs have not yet been overcome, but these early results provide promise and a foothold has been gained. The insights gained may lead to a system of further investigation. The techniques employed in the execution of the treatments in this trial are directly applicable to revegetating heavily weed infested or alienated lands. The application of the techniques used in this trial by grassy ecosystem management practitioners at least on a small scale may help refine and further develop our understanding of the particular influences

on the germination, recruitment and survival of native forbs under field conditions.

7.0 References

Association of Official Seed Analysts (1970). Rules for testing seeds. *Proc. Assoc. Off. Seed Anal.* **60** (2), 116p

Auld, T. D. (1995). Seedling survival under grazing in the arid perennial *Acacia Oswaldii*. *Biological Conservation* **72**(1):27-32.

Avery GSJ, (1933) Structure and germination of tobacco seed and the developmental anatomy of the seedling plant. *American Journal of Botany.* **20**:309-327.

Barlow, T (1998). *Grassy Guidelines How to manage native grasslands and grassy woodlands on your property*. Trust for Nature, Victoria.

Baskin, C. C., and Baskin, J. M. (1988). Germination ecophysiology of herbaceous plant species in a temperate region. *American Journal of Botany* **75**: 286-305

Bennett, A., Brown, G., Lumsden, L., Hespe, D., Krasna, S., and Silins, J. (1998). *Fragments for the Future. Wildlife in the Victorian Riverina (The Northern Plains)*. Department of Natural Resources and Environment, Victoria.

Borchert, Mark I.; Davis, Frank W.; Michaelson, Joel; Oyler, Lynn Dee. (1989). Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. *Ecology.* **70**(2): 389-404.

Bruce, H. (1976). *How to grow wildflowers and wild shrubs and trees in your own garden*. Alfred A. Knopf, Inc., New York.

Chalmers, I (1995). Pasture faces constant pest threat. In *Pasture plus*, M. Casey (ed.) pp. 298-299.

- Clarke P J., Davison, E A, and Fulloon, L. (2000). Germination and dormancy of grassy woodland and forest species: effects of smoke, heat, darkness and cold. *Australian Journal of Botany*. **48**: 687-700.
- Collins, S.L., and Benning, T.L. (1996). Spatial and temporal patterns in functional diversity. Pages 253-280 in K. Gaston, (ed.) *Biodiversity: a biology of numbers and difference*, Blackwell Science, Oxford, UK.
- Cousens, R., and Mortimer, M. (1995). *Dynamics of weed populations*. Cambridge University Press, Melbourne.
- Commonwealth Government (2000). *Environment Protection and Biodiversity Conservation Act* (EPBC).(commonwealth Parliament: Canberra.)
- Craigie, V. and Hocking, C. (eds) (1999). *Down to grass roots: Management of grassy ecosystems*. Keynote addresses and outcomes of the Down to Grass Roots conference at Victoria University in July 1998. Victoria University, Melbourne.
- Cropper, S. (1993). *Management of Endangered Plants* CSIRO Publications, Melbourne
- Department of Natural Resources and Environment (1997). *Victoria's Biodiversity: directions in management. Practical strategy for the Flora and Fauna Guarantee Act 1988*.
- Department of Natural Resources and Environment (1999). *Action Statement no. 53- Western (Basalt) Plains Grassland Community*. Government of Victoria, Melbourne Victoria.
- Diamond J. (1984). *Historic extinctions: A Rosetta Stone for understanding prehistoric extinctions*. In Martin S. and Klein G. eds. (1984) *Quaternary Extinctions: A prehistoric revolution*. Tucson: University of Arizona Press.

- Dixon, K.W., and Roche, S. (1995) *Smoke for Germinating Australian Native Seeds - Inoculation or inhalation and other advances in the propagation of indigenous plants*. Greening Australia, Victoria.
- Edwards, G.R., Crawley, M. J. (1999) Effects of disturbance and rabbit grazing on seedling recruitment of six mesic grassland species, *Seed Science Research*, **9**(2): 145-156.
- Farley R. and Fitter A. (1999) Temporal and spatial variation in soil resources in deciduous woodland. *Journal of Ecology*, **87**, 688.
- Flannery T. (1994) *The Future Eaters*. Reed Books. Victoria, Australia.
- Franke, J. and K. (1993). 'Propagation of *Bursaria spinosa*' *Environmental and Horticultural Considerations for Plant Propagation*, Greening Australia Victoria
- Freeman, C.C. (1998). *The Flora of Konza Prairie A historical review and contemporary patterns*. In *Grassland Dynamics: Long-Term Ecological Research in Tallgrass Prairie*. Knapp, A. K., Briggs, J. M., Hartnett, D. C. and
- Gibson, D.J. & Hulbert, L.C. (1987). Effects of fire, topography and year-to-year climatic variation on species composition in tallgrass prairie. *Vegetation*, **72**:175-185
- Gibson, D.J. (1989). Small-scale animal disturbance effects on tallgrass prairie. *American Midland Naturalist*, **121**:144-154.
- Gibson, D.J., Seastedt, T.R. and Briggs, J.M. (1993). Management practices in tallgrass prairie: large- and small-scale experimental effects on species composition. *Journal of Applied Ecology* **30**: 247-255.
- Gilfedder, L., and Kirkpatrick, J. B. (1994). Genecological variation in the germination, growth and morphology of four populations of a Tasmanian

endangered perennial daisy, *Leucochrysum albicans*. *Australian Journal of Botany* **42**:431-440.

Gott, B. and Conran, J (1998), *Victorian Koorie Plants*. Yangennanock Women's Group, Hamilton, Victoria, Australia.

Government of Victoria (1998) Flora and Fauna Guarantee Act. (Parliament of Victoria; Melbourne.

Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R. Mowforth, M.A.G., Neal, A.M., and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. *Journal of Ecology* **69**,: 1017-1059.

Groves, R.H., Shepherd, R.C.H. and Richardson, R.G. (Eds.) (1995) The Biology of Australian Weeds, Volume 1. R.G and F.J. Richardson Melbourne.

Groves, R.H., Shepherd, R.C.H. and Richardson, R.G. (Eds.) (1998) The Biology of Australian Weeds, Volume 2. R.G and F.J. Richardson Melbourne.

Henderson, M. (2002). Vegetation dynamics in response to burning and slashing in remnants of Western Basalt Plains Grasslands Victoria. PhD thesis, Victoria University, St Albans, Victoria, Australia

Henderson, M. and Hocking, C. (1998). 'How do urban grasslands respond to fire and slashing? Effects on gaps and weediness.' Proceedings of 'Down to Grass Roots' conference, Victoria University, July.

Henderson, M. and Hocking, C. (2000). Why are recruits of common daisies rare events in grasslands? Proceedings of Ecological Society of Australia Annual Conference, La Trobe University, November.

Hodge A., Huchings M. and Wijesinghe D. (1999). Plant, soil fauna and microbial responses to N-availability. *Soil Biology and Biochemistry*, **31**: 1517-1523.

Jordan, W. R., Gilpin, M.E. and Aber, J.D. (eds.)(1990). *Restoration Ecology: A synthetic approach to ecological research*. University Press, Cambridge, Great Britain.

Kaufman, D.W., Kaufman, G.A., Fay, P.A., Zimmerman, J.L. and Evans, E.W. (1998) *Animal populations and communities*". In *Grassland Dynamics: long-term ecological research in tallgrass prairie*. Knapp, A. K., Briggs, J. M., Hartnett, D. C. and Collins, S. L. (Eds). Long-Term Ecological Research Network Series, Oxford University Press.

Kirkpatrick, J., McDougall, K. and Hyde, M (1995). *Australia's most threatened ecosystems: the southeastern lowland native grasslands*. Surrey Beatty and Sons, Chipping Norton, NSW.

Knapp, A. K., Briggs, J.M., Hartnett, D.C. and Collins, S.L. (eds.) (1998). *Grassland Dynamics. long-term ecological research in tallgrass prairie*. Long-Term Ecological Research Network Series, Oxford University Press.

Liu, A and Ridsdill-Smith, T.J. (2000). Feeding by Redlegged earth mite (*Halotydeus destructor*) on seedlings influences subsequent plant performance of different pulse crops. *Australian Journal of Experimental Agriculture*, **40**: 715-723.

Lunt, I. (1990). Impact of an autumn fire on a long-grazed *Themeda triandra* (kangaroo grass) grassland: implications for management of invaded, remnant vegetations. *Victorian Naturalist*, **107**: 45-51.

Lunt ID (1995). Seed longevity of six native forbs in a closed *Themeda triandra* grassland. *Australian Journal of Botany* **43**: 439-449

Lunt, I. (1997). Effects of long-term vegetation management on remnant grassy forests and anthropogenic native grasslands in south-eastern Australia. *Biological Conservation* **81**: 287-297

Lunt I., Barlow T. and Ross, J. (1998). *Plains Wandering: Exploring the Grassy Plains of South-Eastern Australia*. Victorian National Parks Association and The Trust for Nature, Melbourne Australia.

Mason, B. and Hocking, C. (2002). The potential for repair of exotic stipoid grass infested sites with kangaroo grass (*Themeda triandra* Forssk.) with special reference to remnant native grassland. *Plant Protection Quarterly* **17**:3

Mathew, B. (1978) *The larger bulbs*. B.T. Batsford, London

McIntyre, S. (1990). Germination in eight native species of herbaceous dicots and implications for their use in revegetation. *The Victorian Naturalist* **107**:154-158.

McIntyre, S., Lavorel, S., and Tremont, R. M. (1995). Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology* **83**: 31-44. .

Mclvor, J.G. (2002). *Soils*. In *Managing and Conserving Grassy Woodland*. McIntyre, S., Mclvor, J.G. and Heard, K.M. (Eds.) CSIRO Publishing, Collingwood, Vic. Australia.

Mclvor, J.G. and McIntyre S. (2002). *Understanding grassy woodland ecosystems*. In *Managing and Conserving Grassy Woodland*. McIntyre, S., Mclvor, J.G. and Heard, K.M. (Eds.) CSIRO Publishing, Collingwood, Vic. Australia.

Morgan, J. (1995a). Ecological studies of the endangered *Rutidosia leptorrhynchoidea*. I. Seed production, soil seed bank dynamics, population density and their effects on recruitment. *Australian Journal of Botany* **43**: 1-11.

Morgan, J. (1995b). Ecological studies of the endangered *Rutidosia leptorrhynchoidea*. II. Patterns of seedling emergence and survival in a native grassland. *Australian Journal of Botany* **43**: 13-24.

Morgan, J. (1998a). Comparative germination responses of 28 temperate grassland species. *Australian Journal of Botany*, **46**: 209-219.

Morgan, J. (1998b). Importance of canopy gaps for recruitment of some forbs in *Themeda triandra*-dominated grasslands in South-eastern Australia. *Australian Journal of Botany*, **46**: 609-627.

Morgan, J. (1999a). Effects of population size on seed production and germinability in an endangered, fragmented grassland plant. *Conservation Biology* **13**(2) 266-273

Morgan, J. (1999b) Have tubestock plantings successfully established population of rare grassland species into reintroduction sites in western Victoria? *Biological Conservation* **89**: 235-243.

Morgan, J. (2000). Reproductive Success in Re-established versus Natural Populations of a Threatened Grassland Daisy (*Rutidosia leptorrhynchoidea*) *Conservation Biology* **13**(3) 780-785.

Morgan, J. (2001). Seedling recruitment patterns over four years in an Australian perennial grassland community with different fire histories. *Journal of Ecology*, **89**: 908-919.

Norbury, D. C., and Norbury, G. L. (1996). Short-term effects of Rabbit grazing on a degraded short-tussock grassland in central Otago. *New Zealand Journal of Ecology*, **20**(2); 285-288.

Phillips, A., and Hocking, C. (1996) *A method for replacing serrated tussock with weed-free Kangaroo Grass in degraded native grassland remnants.*

Paper presented at the Eleventh Australian Weeds Conference, Melbourne, Australia.

Plummer, J.A., McChesney, C.J. and Bell, D.T. (1994) '*Action via Phytochrome and Gibberrallic Acid in Light Stimulated Germination of Australian Asteraceae*' *Proceedings of National Workshop on Native Seed Biology for Revegetation*, ed Bellairs, S.B. and Bell, L.C., Australian Centre for Minesite Rehabilitation Research, W. A.

Pyrke, A. (1994). *Soil disturbance by native mammals and the germination and establishment of plant species*. Department of Geography and Environmental Studies, University of Tasmania. Hobart.

Ralph, M. (1997). *Growing Australian Native Plants from Seed*. Murray Ralph/Bushland Horticulture, Melbourne, Australia.

Randall, R. (2002). *A global compendium of weeds*. R.G and F.J. Richardson Melbourne.

Ross, J.H. (2000). *A Census of the Vascular Plants of Victoria, sixth edition*. Royal Botanic Gardens Melbourne, Victoria, Australia.

Salisbury, E.J. (1961). *Weeds and Aliens*. Collins, London.

Sindel, B.M., Radford, I.J., Holtkamp, R.H. and Michael, R.W., (1998). *Senecio madagascariensis* Poir. In Groves, R.H., Shepherd, R.C.H. and Richardson, R.G. (Eds.) (1998) *The Biology of Australian Weeds, Volume 2*. R.G and F.J. Richardson Melbourne.

The Australian Daisy Study Group (1983). *Australian Daisies for gardens and floral art*. Lothian, Melbourne.

The Seed Site (2003). The Seed Site. <http://www.theseed site.co.uk>

Trigg, B (1996). *Tracks, Scats and Other Traces. A field guide to Australian Mammals*. Oxford University Press, Melbourne, Victoria, Australia.

United States Department of Agriculture (1974). *Seeds of Woody Plants in the United States. Agriculture Handbook no 450. Chapter 4.5 Viability tests and Chapter 7 Seed Testing*. Forest Service, USDA.

Williams, N., Learly, E. and McDonnell, M. (2000). *The landscape ecology of Melbourne's urban grasslands, Proceedings of Ecological Society of Australia Annual Conference*, LaTrobe University, November.

Wijesinghe, D. and Hutchings, M. (1999). The effects of environmental heterogeneity on the performance of *Glechoma hederacea*: the interactions between patch contrast and patch scale. *Journal of Ecology*. **87**: 860-865

Wijesuriya, S. and Hocking, C. (1998). *Why do weeds grow when you dig up native grasslands. The effects of physical disturbance on available nutrients, mineralisation and weed invasion in native grasslands*. In Craigie, V. and Hocking, C. (eds) (1999). *Down to grass roots: Management of grassy ecosystems*. Victoria University in July 1998. Victoria University, Melbourne.

Wijesuriya, S. (1999). *Investigation of the relationships between biomass reduction, soil disturbance, soil nutrients and weed invasion in basalt plains native grassland remnants in Victoria, Australia*. PhD Thesis School of Life Sciences and Technology, Victoria University, St. Albans, Victoria.

Wuest, S.G., Albrecht, S.S., and Skirvin, K.W. (1999). Vapor transport vs. seed-soil contact in wheat germination. *Agronomy Journal*, **91** (5): 783-787.

Yen, A.L., Horne, P.A., Kay, R. and Kobelt, A.J. (1994). *The use of terrestrial invertebrates to rank sites of the remnant western Victorian basalt plains grassland*. Endangered species Unit, Australian Nature Conservation Agency.

Yen, A. L. (1999) *Overview of the conservation of non-marine invertebrates in Australia*. Appendix in Hutchings, P. A. and Ponder, W.F. Workshop: Criteria for assessing and conserving threatened invertebrates. In Ponder, W. and Lunney, D. (Eds). *The other 99%: The conservation and biodiversity of invertebrates*. Transactions of the Royal Society of NSW.

Young, A.G. and Murray, B.G. (2000). Genetic bottlenecks and dysgenic gene flow into re-established populations of the grassland daisy, *Rutidosia leptorhynchoides*. *Australian Journal of Botany*, **48**: 409-416

Zar, H. (1999). *Biostatistical Analysis*. Simon and Schuster, New Jersey

Appendix 1 Plant descriptions

A total of eighteen herbaceous (forb) species were selected for use in laboratory germination trials with two of these species selected for use in field trials. These species represent a range of forb species found in lowland grassy ecosystems but notably do not include species in the family Fabaceae (the Pea Family). They also represent species that have, for the most part, not been previously studied by other authors (see individual plant descriptions).

Basalt Podolepis

Podolepis sp. 1 (sensu Jeanes 1999)

Asteraceae

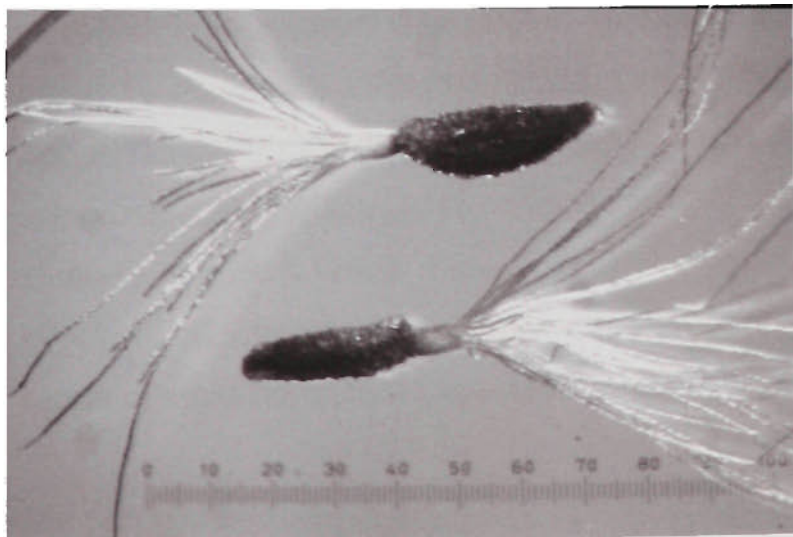


Photo 1 (Above)
Basalt Podolepis
Podolepis sp. 1 Plant

Photo 2 (Left)
Basalt Podolepis
Podolepis sp. 1 Seed

General and Habit Description Basalt Podolepis (*Podolepis* sp. 1 sensu Jeanes 1999) is one of the two species selected for both field and laboratory trials. Basalt Podolepis is a hemicryptophyte in the family Asteraceae. Growth is primarily in the form of basal rosettes to 20cm high and wide. The plants form a taproot with clusters of rosettes but not spatially independent ramets. **Leaves** are up to 10cm long and 1cm wide (usually 2-5mm wide), dark green and slightly hairy. **Flower** heads are produced singly on a leafy inflorescence to 30-40 cm tall, which occasionally branches, producing up to five flower heads. Individual flower heads are 2-3 cm across, bright yellow with a single row of ligulate florets. **Fruit** Achenes are cylindrical, 2mm long with a firmly attached pappus to 1cm long. Seed is primarily short-distance wind-dispersed, generally within a metre of the parent plant, with secondary water and ant dispersal (general observations in this study). Upon wetting the seed emits a gel that completely envelops the germinating seed.

General notes Plants of Basalt Podolepis mature rapidly with flowers first appearing within six months of germination. Plants are generally short-lived in cultivation (3-5 years) but may live longer under ideal conditions in the wild. Mature plants prefer conditions of full sun and good air movement and succumb to fungal disease in shade or conditions of high humidity. Larger growing plants can easily smother Basalt Podolepis, particularly Kangaroo Grass (*Themeda triandra*) with which it commonly occurs.

Habitat notes Basalt Podolepis is a plant of the damper aspects of Lowland Plains Grassland, generally growing in shallow depressions, swales or in the vicinity of exposed basalt rock where soil moisture is higher than the surrounding grassland. Associated species are Kangaroo Grass (*Themeda triandra*), Common Wallaby Grass (*Austrodanthonia caespitosa*), Kneaded Spear Grass (*Austrostipa bigeniculata*), Grassland Bindweed (*Convolvulus remotus*), Cut-leaf Goodenia (*Goodenia pinnatifida*), Blue Devil (*Eryngium ovinum*), Smooth Rice Flower (*Pimelea glauca*), Golden Billy Buttons (*Pycnosorus chrysanthus*), Yellowish Bluebell (*Wahlenbergia luteola*) and a range of other herbaceous species.

Qualifications Urgent taxonomic work is needed to clarify the delimitation of many grassland species (Carr, unpublished data) including species of *Podolepis*. The taxon *Podolepis* sp. 1 was previously included in the more widespread *P. jaceoides* sp. agg. clouding clear distinctions in morphology, ecology, distribution and conservation status. Further resolution of *Podolepis* is needed to clarify the distinctions between *Podolepis* sp. 1 and *Podolepis* sp. aff *jaceoides* (Northern Plains). These apparently distinct taxa may prove to have distinct ecological responses.

Leek Lily

Bulbine semibarbata (R.Br.) Haw. (perennial form)

Asphodelaceae



Photo 3 (Left)
Leek Lily
Bulbine semibarbata
Plant



Photo 4 (Left)
Leek Lily
Bulbine semibarbata
Seed

General and Habit Description Leek Lily (*Bulbine semibarbata*, perennial form) is the second of the two species that were used in both field and laboratory trials. *Bulbine semibarbata*, like *Podolepis* sp. 1, is a hemicryptophyte. *Bulbine semibarbata* is in the family Asphodelaceae. Growth is entirely in the form of basal rosettes to 30cm high and wide though generally to 15cm under normal conditions. The plants form tight clusters of

rosettes with a predominantly fibrous root system and lack the ability to produce spatially independent ramets. **Leaves** The succulent light-green leaves may be up to 30cm long (although generally much shorter) and are terete or semi-terete, 10-25 being produced in each rosette. **Flowers** Flowers are produced in racemes to 50cm tall with as many as 130 flowers in an individual raceme. Normally, several racemes are produced from each rosette, flowering progressively as the raceme elongates, producing an average of 30-50 flowers. Mature seed can be produced at the base of the raceme while flowers are still being produced at the tip of the same raceme. Flowers which are 1-2cm wide are bright yellow with 6 tepals (3 petals and 3 sepals) that all look similar. The individual flowers are strictly diurnal in their opening, and remain open for just one day. Three of the six stamens have clusters of hairs on them. **Fruit** Seeds are produced in a three-chambered capsule, which contain an average of 10-20 small, angled, seeds that are approximately 2mm across. Seed is primarily short-distance dispersed (mechanical) with secondary water and ant dispersal (General observation in this study).

General notes Growth of *Bulbine semibarbata* is generally rapidly from seed; with first flowers appearing within six months of germination. Longevity of the individual plants is generally short (3-5 years) in cultivation but is prolonged when plants are moderately stressed and of slower growth. Plants grow equally well in sun or shade with plants in full sun being reduced in size and more succulent. Flowering and growth can be continuous under garden conditions and shaded well-watered conditions in the wild.

Habitat notes At present the form being used is known from three localities in the Melbourne area with one of these sites close to the study site but is generally assumed to be more widespread but overlooked. The three known sites are all open grassy woodland with Yellow Box (*Eucalyptus melliodora*) as the overstorey species. *Podolepis* sp. 1 and *Bulbine semibarbata* generally grows near to exposed rock and in areas where competition from other forbs is reduced. Associated herbaceous species include Kangaroo Grass (*Themeda triandra*), Slender Wallaby Grass (*Austrodanthonia racemosa*),

Veined Spear Grass (*Austrostipa rudis* ssp. *rudis*), Weeping Grass (*Microlaena stipoides*), Tall Bluebell (*Wahlenbergia stricta*), Common Riceflower (*Pimelea humilis*) and Stinking Pennywort (*Hydrocotyle laxiflora*). Several shrubs and sub-shrubs occur as scattered individuals throughout the understorey, including Hedge Wattle (*Acacia paradoxa*), Shiny Cassinia (*Cassinia longifolia*), Burgan (*Kunzea ericoides*), and Honey-pot Heath (*Acrotriche serrulata*).

Qualifications The various taxa within the genus *Bulbine* in South-eastern Australia are in need of taxonomic revision. The form of *Bulbine semibarbata* used in this study differs from the more widespread small annual taxon commonly known as *Bulbine semibarbata*. Differences in the two taxa relate not only to morphological characteristics but also to ecological preferences. Recent taxonomic work has recognised Rock Lily (*Bulbine glauca*) and several undescribed taxa of succulent perennial *Bulbine* similar to the form of *Bulbine semibarbata* used in this study.

Small Vanilla-lily
Arthropodium minus R. Br.

Athericaceae

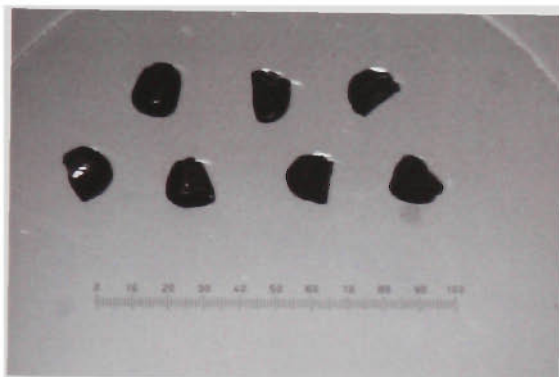


Photo 5 (Above)
Small Vanilla Lily *Arthropodium minus*
Plant

Photo 6 (Left)
Small Vanilla Lily *Arthropodium minus*
Seed

Notes Small vanilla lily is a small winter-growing geophyte to 20cm tall. This species reproduces by seed only. Small vanilla lily grows in the shallow soil surrounding and over large rocks and submerged boulders. This habitat does not support large perennial forbs and grasses. Common companion plants in these specific shallow soil habitats are stonecrops (*Crassula* species), rock ferns (*Cheilanthes* species), rye beetle-grass (*Tripogon lolliformis*) and several annual forb species. .

Chocolate Lily

Arthropodium strictum R. Br.

Athericaceae



Photo 7 (Above)
Chocolate Lily *Arthropodium strictum*
Plant

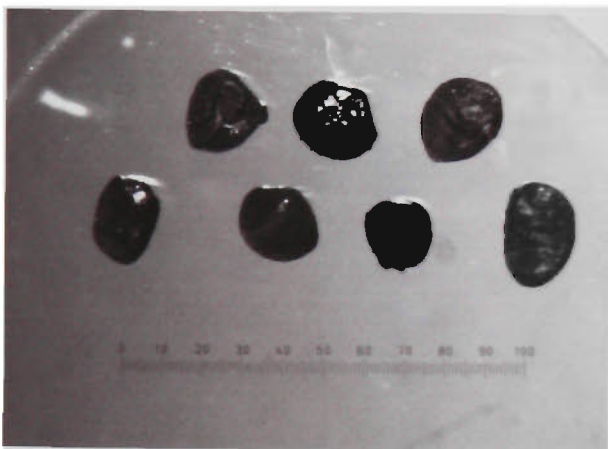


Photo 8 (Left)
Chocolate Lily *Arthropodium strictum*
Seed

Notes Chocolate lily is a winter-growing geophyte to 50cm tall. Reproduction is from seed only. Although similar to small vanilla lily it is altogether a more robust plant. Chocolate lily occurs in a wide range of grassy ecosystems from open plains to grassy-forest but does not grow in waterlogged soils. This species prefers moderate to deep soils. Common companion plants include kangaroo grass (*Themeda triandra*), wallaby grasses (*Austrodanthonia* species) and a wide range of forbs, shrubs and trees.

Tall Daisy

Brachyscome diversifolia (Graham ex Hook) Fisch. & C.A. Mey
ssp. *diversifolia*

Asteraceae



Photo 9 (Left)
Tall Daisy
Brachyscome diversifolia
ssp. *diversifolia*
Plant

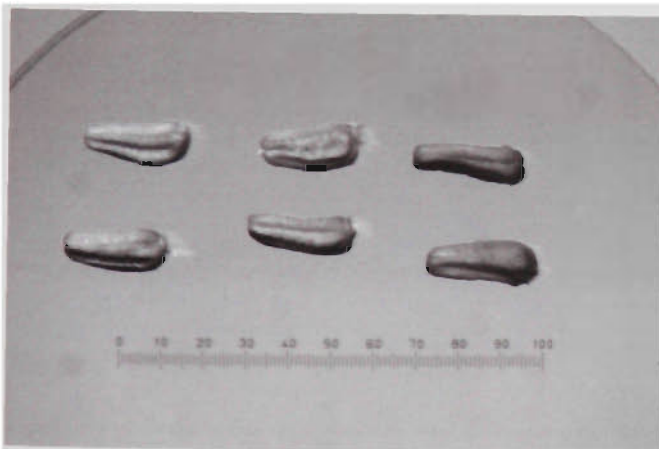


Photo 10 (Left)
Tall Daisy
Brachyscome diversifolia
ssp. *diversifolia*
Seed

Notes Tall daisy is a short-lived perennial hemicryptophyte forming small rosettes of leaves to 10cm with single flowered scapes to 30cm tall. Reproduction is from seed only. Like small vanilla-lily, tall daisy is a plant of rock outcrops and shallow soils where there is little competing plant growth. Rock ferns (*Cheilanthes* species), Stonecrops (*Crassula* species) and necklace fern (*Asplenium flabellifolium*) are common associates.

Swamp Everlasting

Bracteantha palustris Flann

Asteraceae



Photo 11 (Above)
Swamp Everlasting
Bracteantha palustris
Plant



Photo 12 (Left)
Swamp Everlasting
Bracteantha palustris
Seed

Notes Swamp everlasting is a long-lived strongly rhizomatous hemicryptophyte growing to 50cm or more tall. Reproduction is by seed or vegetative spread. Individual plants may spread to form colonies of over two metres wide after two years of growth. Swamp everlasting, as the name implies, is a plant of periodically inundated sites including grassy wetland and the damper aspects of Plains Grassland. Common associated plants include blown grasses (*Agrostis* species), billy buttons (*Pycnosorus* species) and a range of herbaceous plants.

Sticky everlasting

Bracteantha viscosa (DC.) Anderb. & Haegi

Asteraceae



Photo 13 (Above)
Sticky Everlasting
Bracteantha viscosa
Plant

Photo 14 (Left)
Sticky Everlasting
Bracteantha viscosa
Seed

Notes Sticky everlasting is a short-lived perennial hemicryptophyte forming clumps of stems to 40cm tall. Reproduction is from seed only. Sticky everlasting is a plant of the drier aspects of grassy ecosystems. Plants that are commonly found in association with sticky everlasting are Wallaby Grasses (*Austrodanthonia* species), several herbaceous goodenias (*Goodenia* species), gold-dust wattle (*Acacia acinacea*) and a range of herbaceous and woody species.

Bulbine Lily

Bulbine bulbosa (R. Br.) Haw.

Asphodelaceae

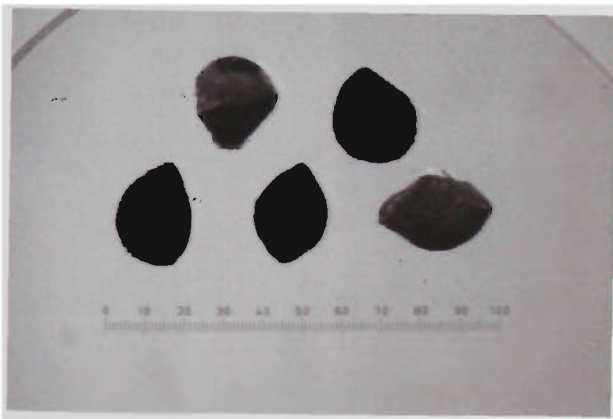


Photo 15 (Above)
Bulbine Lily
Bulbine bulbosa
Plant

Photo 16 (Left)
Bulbine Lily
Bulbine bulbosa
Seed

Notes Bulbine lily is a winter-growing geophyte that grows to 40cm tall. Reproduction is from seed only. Bulbine lily is a common associate of Chocolate lily with both forming extensive colonies on moderate to deep relatively fertile soils. Common associated plants include kangaroo grass (*Themeda triandra*), weeping grass (*Microlaena stipoides*) and a range of daisies and peas.

Hoary Sunray

Leucochrysum albicans (A. Cunn.) Paul G. Wilson
ssp. albicans var. *albicans*

Asteraceae



Photo 17 (Above)
Hoary Sunray
Leucochrysum albicans
ssp. albicans var. *albicans*
Plant

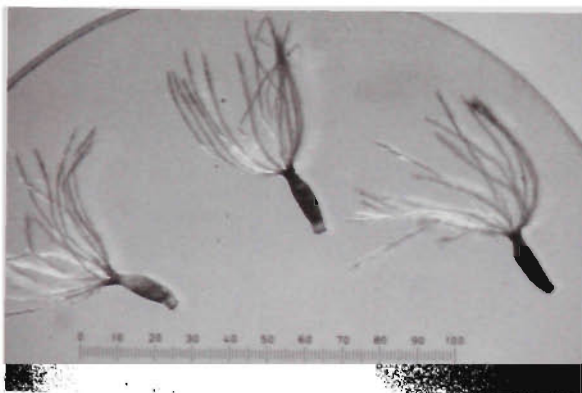


Photo 18 (Left)
Hoary Sunray
Leucochrysum albicans
ssp. albicans var. *albicans*
Plant

Notes Hoary sunray is a small clump-forming hemicryptophyte usually not more than 10-15cm tall. Reproduction is from seed only. Hoary sunray is a plant of open and exposed sites with reduced competition from other larger plants. The variety described here occurs only in the drier grassy forest ecosystems found on Silurian soils. Common associated plants include wattle mat-rush (*Lomandra filiformis*), Wallaby grasses (*Austrodanthonia* species), blue pincushions (*Brunonia australis*) and a range of other herbaceous plants.

Hoary Sunray

Asteraceae

Leucochrysum albicans (A. Cunn.) Paul G. Wilson
ssp. albicans var. tricolor (DC.) Paul G. Wilson



Photo 19 (Above)
Hoary Sunray
Leucochrysum albicans
ssp. albicans var. tricolor
Plant



Photo 20 (Left)
Hoary Sunray
Leucochrysum albicans
ssp. albicans var. tricolor
Seed

Notes Hoary Sunray is a small clump-forming hemicryptophyte to 15cm tall. Reproduction is from seed only. This variety of *Leucochrysum albicans* only occurs on the drier aspects of the grasslands and grassy woodlands found on Ordovician soils associated with the Southern Grampians in Victoria. Commonly associated plants include kangaroo grass (*Themeda triandra*), common everlasting (*Chrysocephalum apiculatum*) and a range of lily and pea flowers.

Yam Daisy

Microseris sp. 3 (sensu Jeanes 1990)

Asteraceae



Photo 21 (Left)
Yam Daisy
Microseris sp. 3
Plant

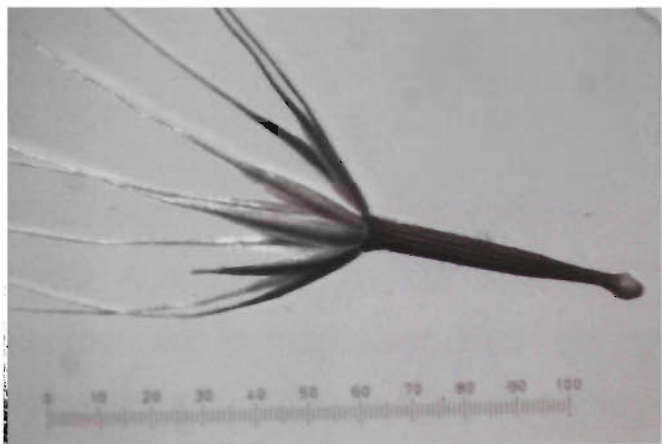


Photo 22 (Left)
Yam Daisy
Microseris sp. 3
Seed

Notes Yam daisy is a small winter-growing geophyte growing to 30cm tall. Reproduction is from seed only. This is the most common of the four taxa formerly included in *Microseris scapigera/lanceolata*. It is widespread, but not common, in the grassy forests of south-eastern Australia.

Australian Buttercup

Ranunculus lappaceus Sm.

Ranunculaceae



Photo 23 (Above)
Australian Buttercup
Ranunculus lappaceus
Plant



Photo 24 (Left)
Australian Buttercup
Ranunculus lappaceus
Seed

Notes Australian Buttercup is a winter-growing clump-forming geophyte. Reproduction is from seed only. This buttercup grows in a range of grassy ecosystems in south-eastern Australia from treeless grassland to grassy forests. In higher rainfall areas Australian buttercup is associated with the drier aspects of the environment while in lower rainfall areas it is associated with drainage lines or seasonally wet areas. Tussock grasses (*Poa* species), weeping grass (*Microlaena stipoides*) and a wide range of herbaceous plants are common associates.

Chamomile Sunray

Rhodanthe anthemoides (Spreng.) Paul G. Wilson

Asteraceae



Photo 25 (Above)
Chamomile Sunray
Rhodanthe anthemoides
Plant

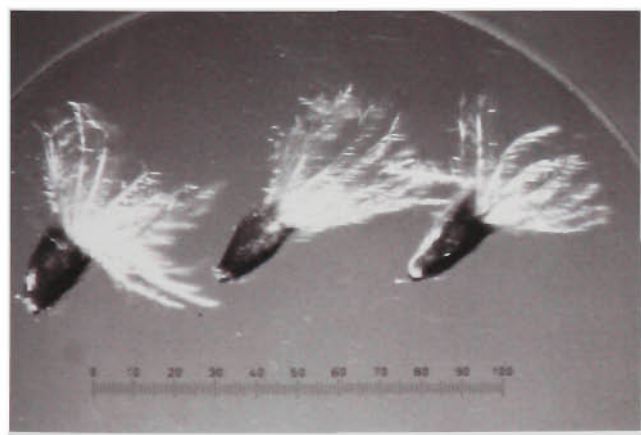


Photo 26 (Left)
Chamomile Sunray
Rhodanthe anthemoides
Seed

Notes Chamomile sunray is a clump-forming hemicryptophyte growing to about 20cm tall. Reproduction is from seed only. Chamomile sunray is widespread in eastern Australia and occurs in a range of habitats. The form used in this study is restricted to rocky-outcrops within the Keilor basalt plain. Common associated plants include kneed wallaby-grass (*Austrodanthonia geniculata*), rock-fern (*Cheilanthes seiberi*), kangaroo grass (*Themeda triandra*) and a range of other herbaceous plants.

Large-fruit Groundsel

Senecio macrocarpus Belcher

Asteraceae



Photo 27 (Above)
Large-fruit Groundsel
Senecio macrocarpus
Plant

Photo 28 (Left)
Large-fruit Groundsel
Senecio macrocarpus
Seed

Notes Large-fruit groundsel is a clump-forming short-lived perennial hemicryptophyte growing to 40cm tall. Reproduction is from seed only. Large-fruit groundsel is a plant of the open treeless plains of south-eastern Australia. Once a common plant it is now restricted to a few populations. Common associated plants include kangaroo grass (*Themeda triandra*), common everlasting (*Chrysocephalum apiculatum*), Blue Devil (*Eryngium ovium*), and a wide range of herbaceous species.

Tall Groundsel

Senecio runcinifolius J.H. Willis

Asteraceae



Photo 29 (Above)
Tall Groundsel
Senecio runcinifolius
Plant



Photo 30 (Left)
Tall Groundsel
Senecio runcinifolius
Seed

Notes Tall Groundsel is a short-lived perennial hemicryptophyte growing to 1m tall. Reproduction is from seed only. Like swamp everlasting, tall groundsel is associated with the damper aspects of grasslands though rarely if ever growing in areas that are inundated. Tall groundsel is more usually associated with the edges of swamps and damp grasslands that are only inundated for very short periods of time. Commonly associated species include tussock grasses (*Poa* species), blown grasses (*Agrostis* species), swamp-wallaby grasses (*Amphibromus* species) and a range of moisture-loving herbaceous species.

Forest Germander

Teucrium corymbosum R. Br.

Lamiaceae



Photo 31 (Above)
Forest Germander
Teucrium corymbosum
Plant



Photo 32 (Left)
Forest Germander
Teucrium corymbosum
Seed

Notes Forest germander is a long-lived hemicryptophyte growing to 50cm tall but can become suffruticose and reach a height of 1m in full flower. Reproduction is from seed only. In south-central Victoria, forest germander is a species of grassy dry woodlands and forests and shaded grassy gullies with an overstorey of yellow gum (*Eucalyptus leucoxylon*) and yellow box (*Eucalyptus melliodora*). The understorey of these woodlands and forests contain wallaby grasses (*Austrodanthonia* species), tussock grasses (*Poa* species), clustered everlasting (*Chrysocephalum semipapposum*) and a wide range of geophytic species.

Showy Violet

Viola betonicifolia Sm. ssp. *betonicifolia*

Violaceae



Photo 33 (Above)
Showy Violet
Viola betonicifolia
ssp. *betonicifolia*
Plant

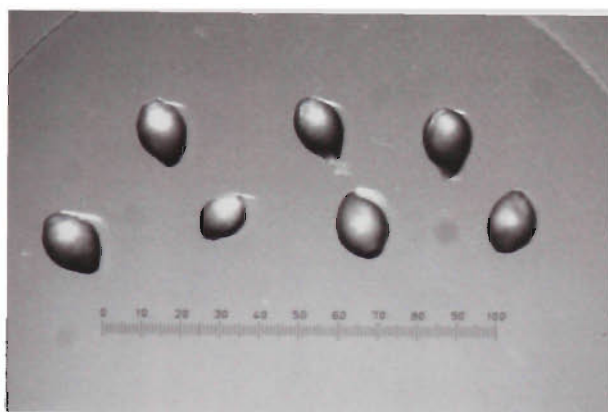


Photo 34
Showy Violet
Viola betonicifolia
ssp. *betonicifolia*
Seed

Notes Showy violet is a small clump-forming hemicryptophyte growing to 15cm tall. Reproduction is primarily by seed but plantlets occasionally form on roots allowing the plant to form small colonies. Showy violet is a plant of moist deep soils and is commonly found in valleys that contain grassy woodlands and forests. The most common associates are weeping grass (*Microlaena stipoides*), kidney weed (*Dichondra repens*), bulbine lily (*Bulbine bulbosa*) and hairy speedwell (*Veronica calycina*).

