Population decline and potential for local extinction in a population of *Pultenaea glabra* (Fabaceae) in Victoria

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***Abstract**:* *Pultenaea glabra* Benth. is a recently revised taxon which includes disjunct populations in Victoria, NSW, and Queensland. Victorian populations were previously described as *Pultenaea weindorferi* Reader, and listed as rare in Victoria. *Pultenaea glabra* is known from four locations in Victoria; it is locally abundant at the Bunyip and Lerderderg-Wombat localities, is uncommon at Wandin, and is in serious decline at Kinglake. Viable soil-stored seeds were present at all sampled locations, and seed germination was enhanced by heat pre-treatments, though germination of untreated seeds also occurred. Few mature plants remain at Kinglake and the population structure differed markedly from the other sampled populations. It has been suggested that the species requires a specific fire regime for regeneration, but it is likely that the severe decline in the Kinglake population is the result of grazing, rather than an inappropriate fire regime. At this site, germination is occurring but plants have not reached maturity, and the species is represented by only seedlings. Managing the species at Kinglake will require consideration of multiple factors, and reintroducing fire to the site at this stage may jeopardize seedling survival and result in local extinction.

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Introduction

For many species, seedling recruitment into fire-prone plant communities relies on seedbank exposure to fire related cues such as heat shock and smoke (Williams et al. 2003). Factors such as seedbank size, seed longevity and depth of seed burial affect germination and recruitment (Tozer 1998, Auld et al. 2000, Brown et al. 2003), and the relative frequency of fire influences the replenishment of seed in the seedbank and population structure (Bradstock et al. 1997). Population structure for individual species is also influenced by the proportion of non-dormant seed in the seedbank (Auld et al. 2000). Obligate seeders are particularly vulnerable to altered fire regimes, and very frequent or very infrequent fires have the potential to contribute to local species extinctions (Bradstock et al. 1998).

Pultenaea glabra Benth. (Fabaceae) is a shrubby obligate seeder and is believed to be dependent on a specific fire regime for regeneration (de Kok & Weston 2002). *Pultenaea glabra* is a slender, erect, usually glabrous shrub growing up to 2 m in height, with yellow flowers in clusters near the ends of branches. It usually occurs as discrete populations within seasonally swampy heath, shrubby woodland and open forest (Reader 1905, Galbraith 1977, Corrick 1980, Woolcock 1989, Walsh & Entwisle 1996, de Kok & Weston 2002). *Pultenaea glabra* includes disjunct populations on the Tablelands and Central Western Slopes of NSW, and Queensland (de Kok & Weston 2002). In Victoria it is known from only four localities: Lerderderg State Park and adjacent Wombat State Forest; Bunyip State Park; Wandin area; and Kinglake National Park (Fig. 1). At Lerderderg and Bunyip

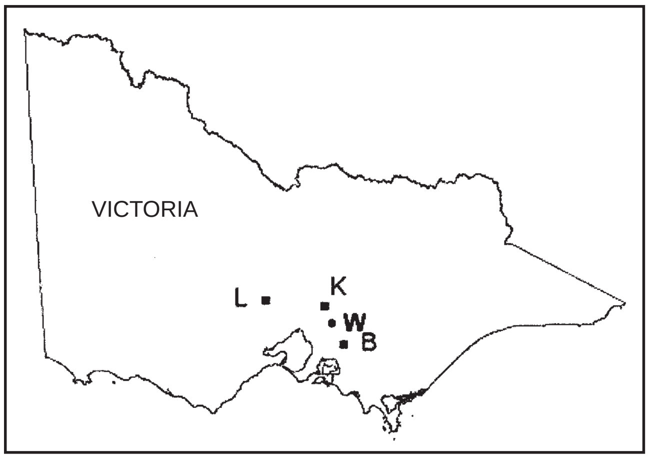


Fig. 1. Locations of *Pultenaea glabra* populations in Victoria. ■ sampled sites L = Lerderderg, K = Kinglake, B = Bunyip; ● not sampled W = Wandin.

the species is locally abundant, and there are many populations with large numbers of individuals present; at Wandin, fewer than 30 plants were located in one population. The population of *Pultenaea glabra* at Kinglake has declined markedly between 1996 and 1999, and now appears to be vulnerable to local extinction. The entire population at Kinglake was burnt in 1962 (McMahon & Stuwe 1982), and some areas were also burnt in 1971 and 1981 (McMahon & Stuwe 1982, Parks Victoria 2001). In 1982, a survey of the 1962-burnt site noted that there were few adult plants, while the areas burnt in 1971 and 1981 had abundant *Pultenaea glabra* plants (McMahon & Stuwe 1982, Woolcock 1989).

In 1996, thousands of mature plants were recorded at Kinglake (N.Walsh, Senior Conservation Botanist, Melbourne Herbarium, Royal Botanic Gardens, pers. comm.) but this population has dramatically declined in numbers, and by 1999 no mature plants could be found (T. Fitzgerald, Ranger, Kinglake National Park, pers. comm.). No mature plants, and remarkably, few dead stems, were located during sampling in 2001 (Fraser 2001). Following natural senescence, at least some dead stems of *Pultenaea glabra* would still be present at the site, which suggests that natural senescence is unlikely to be responsible for the population decline at Kinglake.

Pultenaea glabra is generally believed to be hard-seeded, responding to fire by mass germination, and to display a population structure consistent with discrete recruitment events. Scarlett and Parsons (1993) suggested that low seedling recruitment and the decline in the Kinglake population were caused by changes in fire regime. However, the germination behaviour of NSW populations of *Pultenaea glabra* indicated that they had a large non-dormant seed fraction, and that germination occurred whenever conditions were favourable (Auld 1991, Auld & O'Connell 1991, Morrison et al. 1992). Therefore, if seedlings recruiting in the inter-fire interval fail to reach maturity, the continued conversion of seeds from dormant to a non-dormant state and subsequent germination may severely deplete the seed-bank. The persistence of the Kinglake population is of concern to managers and it has been suggested that reintroducing fire will re-establish this population (T. Fitzgerald, Ranger, Kinglake National Park, pers. comm.). However, simple re-instatement of an ecological process such as fire is unlikely to result in restoration of the population, especially where other components of the ecosystem have been altered (Hobbs & Norton 1996). Exotic herbivores such as deer (Moriarty 2004), goats and rabbits are now part of the Kinglake ecosystem and are known from other studies to affect the success of post-fire vegetation recovery (Cohn & Bradstock 1997). This study aimed to assess the soil-stored seed bank, its germination potential, population structure, site floristics, and soil characteristics of Victorian populations of *Pultenaea glabra*, with a focus on the management implications for the Kinglake population.

Methods

Pultenaea glabra Benth. (Fabaceae) is a recently revised taxon with populations in Victoria, NSW and Queensland (de Kok & Weston 2002). Victorian populations were previously described as *Pultenaea weindorferi* Reader, and this species was listed as rare in Victoria and nationally (Gullan et al. 1990, Briggs & Leigh 1996). The Victorian population at Kinglake displays some taxonomic differences from other populations, having long, soft hairs on the calyx and leaves (Corrick 1980), though it is within the morphological range of *Pultenaea glabra* (Walsh & Entwistle 1996, de Kok &Weston 2002).

Distribution

Collection records from the Melbourne Herbarium, and records and information from other sources (Barry Kemp, ex Department of Conservation Forests and Lands, pers. comm., Stuwe 1980, Kemp 1985) were collated, and all known locations were visited to confirm the presence of *Pultenaea glabra*. Sample sites were selected at representative areas along Buttongrass Track, Bunyip State Park (38º03'S, 145º37'E), O'Brien's Road, Lerderderg State Park (37º29'S, 144º25'E), and from the entire Kinglake National Park site (37º34'S, 145º20'E). The Wandin population was not sampled due to the small number of individuals.

Soil-stored seed

Soil samples were taken to a depth of 5 cm, as most seeds are found within this layer (Hodgkinson et al. 1980, Tozer 1998, Lynch 1999). Twenty-one soil cores were collected at 1 m intervals along two 10 m transects placed perpendicular to each other, and with a mature plant at the intersection of the transects. Each soil core was taken using a 5 cm diameter metal cylinder, and separated into 0–2 cm and 2–5 cm layers. This sampling design was repeated 24 times at Kinglake (504 cores) and six times (126 cores) at Bunyip and Lerderderg. Each soil sample was sieved and examined under a dissecting microscope to recover *Pultenaea glabra* seeds. Seed numbers were recorded separately for the 0–2 cm and 2–5 cm layers, and then bulked for the germination trial. Seed numbers were compared between populations and depths using two-way ANOVA. Data were examined for normality and homogeneity of variances, and the data $\log_{10}$ transformed for analysis. The differences between significant means were examined using Newman-Keuls multiple comparisons test.

Seed bank germination

Seeds from each location were divided into replicates of 20 seeds. Five replicates were heat treated with boiling water for 2 minutes and left to soak for 12 hours, while another 5 replicates (controls) were treated with water at room temperature. Seeds were germinated in a controlled temperature cabinet at 18°C and checked daily for 45 days. After 45 days, ungerminated control seeds were heat treated and left to germinate to establish viability. All germination data were converted to percentages, arcsin transformed, and means compared using one-way ANOVA and a Newman-Keuls multiple comparisons test.

Population structure and characteristics

Population structure was determined by measuring the height and stem diameter of each plant and constructing size-class diagrams. The number of primary branches was counted and used to indicate grazing level (Clunie & Becker 1991). Flowering status, and adult or seedling status (plant <30 cm high) were also assessed. Observations suggested that, while some plants smaller than 30 cm reached maturity and flowered, most flowering plants were greater than 30 cm in height, and a height of 30 cm was arbitrarily chosen for the assignment of individuals into seedling or mature categories. Plant health was estimated on a subjective basis: 'good' = all green foliage and flowering, 'moderate' = some green foliage but remainder of plant is dying, or 'dead' = a stem without any green foliage. At Bunyip and Lerderderg, these variables were measured for all plants in 15 randomly placed 5 × 5 m quadrats, while at Kinglake, the whole site was divided into twelve 50 × 50 m grids and one 5 × 5 m quadrat was sampled randomly within each grid.

Floristics

Vascular plant species were sampled using 3 × 3 m quadrats located within, and adjacent to *Pultenaea glabra* patches, to determine if species composition within populations was floristically distinct. Quadrat size was chosen following construction of species-area curves (Kershaw & Looney 1985). At Bunyip and Lerderderg five quadrats were sampled within, and four quadrats were sampled adjacent to, a *Pultenaea glabra* stand, and at Kinglake, six quadrats were sampled within the stand and eight adjacent to the stand. *Pultenaea glabra* was excluded from the analysis to avoid confounding effects (Coates et al. 1999), and one quadrat at Kinglake was excluded due to having only *Pultenaea glabra* seedlings and no other species present.

Floristic data (based on presence/absence of species) were analysed using the multivariate analysis program PRIMER (Clarke & Gorley 2000), and cluster analysis and non-metric multidimensional scaling was used to elucidate floristic patterns. The Bray-Curtis similarity measure was used to construct the similarity matrix, and clustering used complete linkage.

Soil characteristics

Soil characteristics were examined to establish whether the apparent discreteness of *Pultenaea glabra* populations could be related to soil differences. Within each of the quadrats used for floristics, a random soil core was examined to 50 cm depth. Soil texture, soil pH (CSIRO soil pH test kit) and soil colour (Munsell Soil Color Chart) were assessed in 10 cm depth increments. Resistance to penetration was measured using a Humboldt Pocket Penetrometer, and used as an indirect measurement of topsoil compaction. Three measurements were taken in each floristic quadrat and averaged to produce a representative compaction value for each quadrat. Within stand means and adjacent means were compared using one-way ANOVA and a Newman-Keuls multiple comparisons test.

Results

Soil-stored seed

ANOVA results indicated a significant interaction between populations and soil depth ($F_{2,66}=8.46$, $p<0.001$) indicating that the variation is population dependent. Newman-Keuls multiple comparisons tests showed that the mean number of seeds at 2–5 cm depth was not significantly different ($p<0.05$) for the three populations. At Kinglake, the number of soil-stored seeds was not significantly different between the two depths, however Kinglake had significantly fewer seeds at 0–2 cm depth compared with 0–2 cm depth at Lerderderg and Bunyip (Fig. 2). Although the total number of seeds recovered from the three locations was similar, sampling intensity at Kinglake was four times that for Lerderderg or Bunyip and, on a per litre of soil basis, seed density in the 0–2 cm soil layer at Kinglake was very low (Table 1).

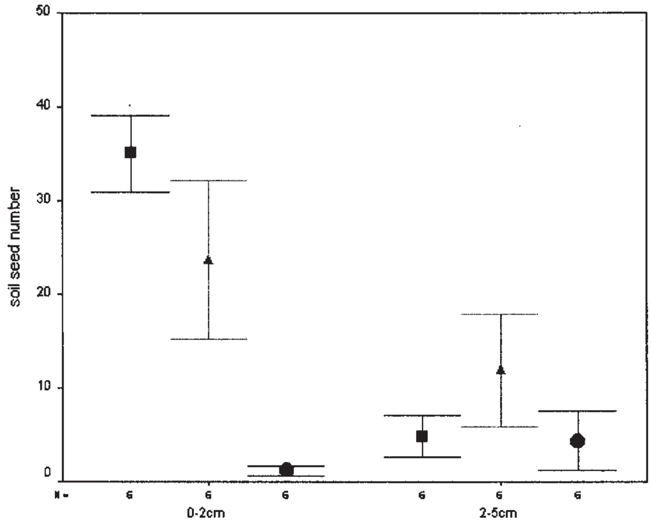


Fig. 2. Seed number (mean ± SE) from two depths for three populations of *Pultenaea glabra*. Lerderderg (■), Bunyip (▲), Kinglake (●).

Table 1. Total soil seed numbers and seed densities (±SE) at two depths for three populations of *Pultenaea glabra*. n = number of samples per population; each sample comprised 21 soil cores.

Location	n	Seed numbers			Seed density (seed/L soil)	
		0–2cm	2–5cm	total	0–2cm	2–5cm
Lerderderg	6	210	29	239	42.7±5.00	3.9±1.77
Bunyip	6	142	69	211	29.0±10.24	13.5±7.48
Kinglake	24	94	186	280	4.8±1.25	6.4±1.68

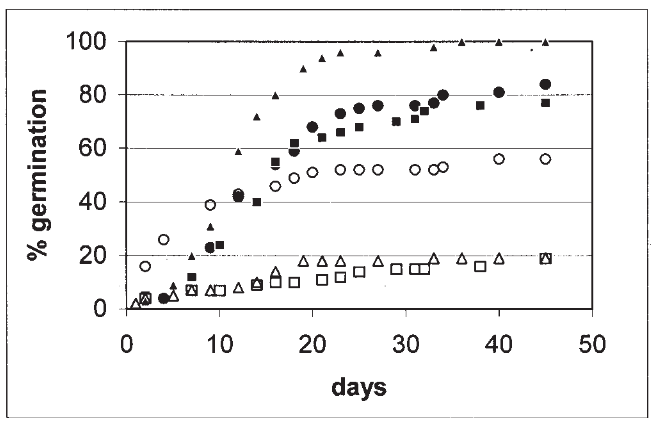


Fig. 3a. Germination (%) of soil-stored seeds of *Pultenaea glabra* at Lerderderg (■), Bunyip (▲), and Kinglake (●); solid symbols = heat treatment, open symbols = controls.

Seed bank germination

Soil stored seed of *Pultenaea glabra* was viable at all three sites. Most seeds had germinated by 25 days and germination reached maximum levels by 40 days (Fig. 3a). Heat treatment of seeds resulted in significantly higher levels of successful germination ($F_{5,24}$=24.37, $p<0.001$) compared with untreated seeds (Fig. 3b). Final germination of seeds from Lerderderg (77%) was not significantly different from Kinglake (84%), but germination of Bunyip seeds (100%) was significantly higher ($p<0.05$, Fig. 3b) than both Lerderderg and Kinglake

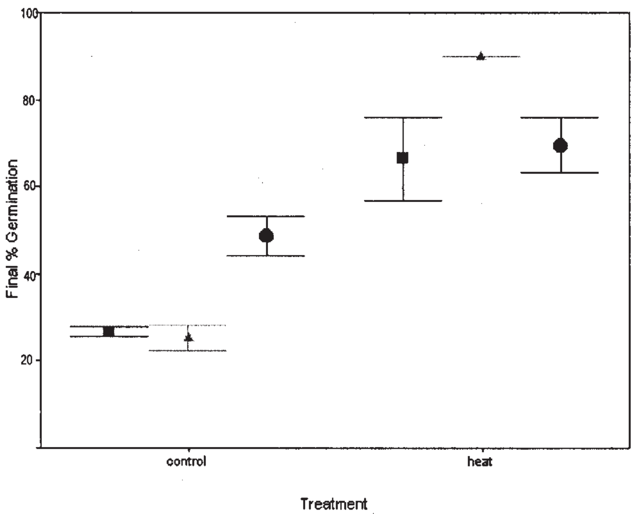


Fig. 3b. Total germination (%) of soil-stored seed (mean ± SE) for three populations of *Pultenaea glabra* at Lerderderg (■), Bunyip (▲), and Kinglake (●).

A relatively high proportion of untreated (control) seeds germinated. Both Bunyip and Lerderderg had similar untreated germination percentages (20%), while a significantly higher proportion (56%) of untreated seeds from Kinglake germinated ($p<0.05$, Fig. 3b). All ungerminated seeds from the control treatments germinated following heat treatment.

Population structure and characteristics

Lerderderg and Bunyip populations had similar size distributions, with most plants 1–1.8 m high (Fig. 4). Lerderderg had more slightly larger plants over 150 cm, while Bunyip had slightly more plants less than 150 cm, but the range in heights was very similar. Stem diameters ranged from 0.6–1 cm; only height data are presented. Height was used as a surrogate for plant age. Variations in growth resulting from density effects, and local site conditions would normally result in a range of height and girth size classes for any given age of plants, however sufficiently strong correlations have been found between plant height and plant age for a number of different species (eg. Hazard & Parsons 1977, Stoner 2001) to justify the cautious use of height as an estimate of age. If height data is a good surrogate for age, then the distribution of height classes suggests a steady background level of recruitment of seedlings into these populations (Bowkett & Kirkpatrick 2003), which is consistent with the levels of seed able to germinate without a heat stimulus. The population at Kinglake shows a very different structure, with predominantly

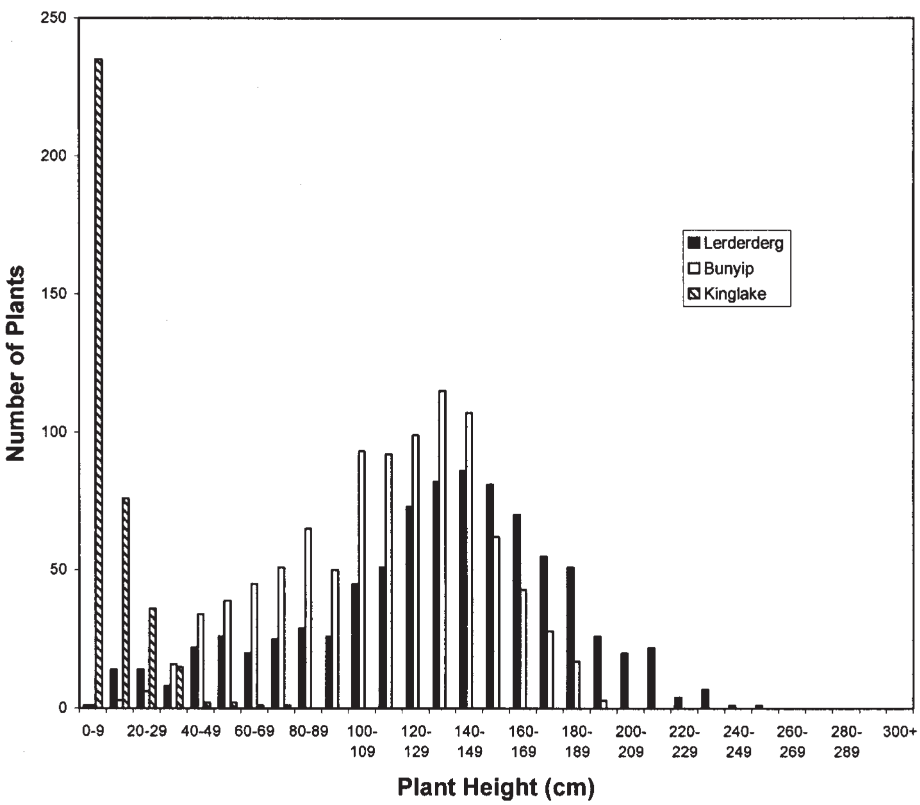
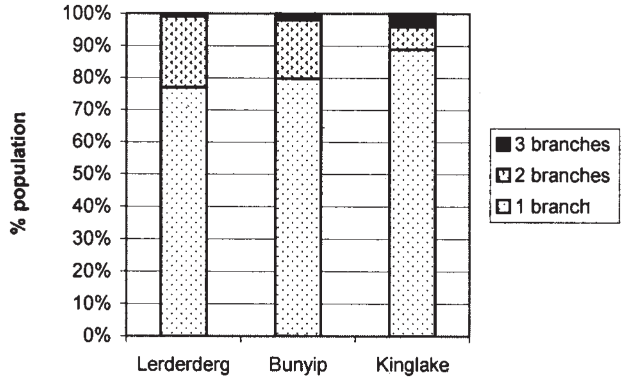
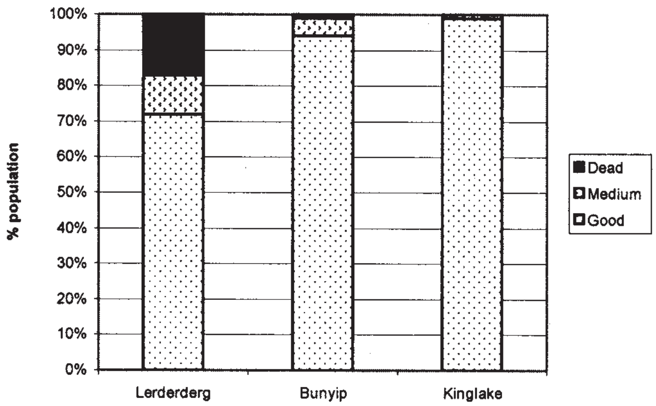


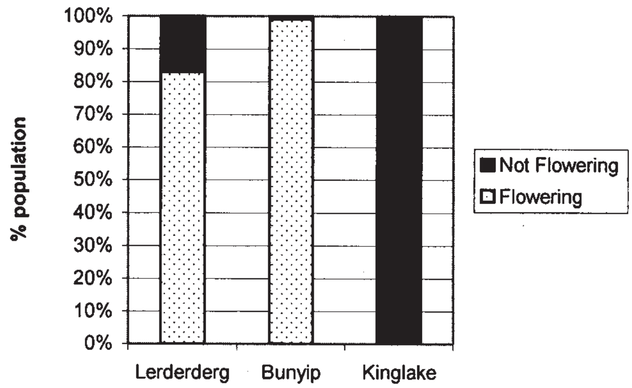
Fig. 4. Plant Height histograms in 10 cm height classes for three populations of *Pultenaea glabra.*



(a) branching



(b) health



(c) flowering

Fig. 5. Branching (a), shrub health (b), and flowering (c) in three populations of *Pultenaea glabra* in Victoria.

immature plants less than 20 cm high, and stem diameters less than 0.5 cm. This suggests a significant difference to the recruitment pattern identified at the other two locations.

Most plants at each of the three locations had one or two primary branches (Fig. 5a), though the Bunyip and Kinglake populations had a small proportion of plants with three primary stems. At Bunyip, this was consistent with the overall larger size of plants, but at Kinglake, where 94% of plants were seedlings, it may indicate more frequent re-shooting following widespread and severe tip pruning by herbivores (Clunie & Becker 1991). Estimates of plant health suggest all three populations are in good condition (Fig. 5b). Most plants sampled at Lerderderg and Bunyip were in flower, while at Kinglake no plants were observed flowering (Fig. 5c), reflecting the immaturity of all plants in that population.

Floristics

Cluster analysis (Fig. 6) and multidimensional scaling (MDS) (Fig. 7) suggest that at Bunyip and Lerderderg, the floristics of the area in which *Pultenaea glabra* grows are subtly different from the adjacent area as there was a general separation between quadrats containing *Pultenaea glabra* and those that did not. At Kinglake the floristic composition within and adjacent to the stand was more homogeneous.

Soil characteristics

Bunyip and Kinglake had loam topsoils over silty loam or clay loam at 50 cm, and Lerderderg had silty clay loam topsoil over light clay at 10 cm and medium clay at 50 cm (Table 2). There were few significant detectable differences in soil characteristics within the *Pultenaea glabra* populations compared to adjacent areas, other than soil penetration resistance ($F_{5,28}=47.73$, $p<0.001$). Bunyip soils showed least resistance, with no differences between areas within and adjacent to *Pultenaea glabra*. Soil resistance in adjacent sites was twice that within *Pultenaea glabra* sites ($p<0.05$) at Lerderderg, while at Kinglake, topsoils were the same throughout, but were nearly five times more compacted than the Bunyip soils ($p<0.05$).

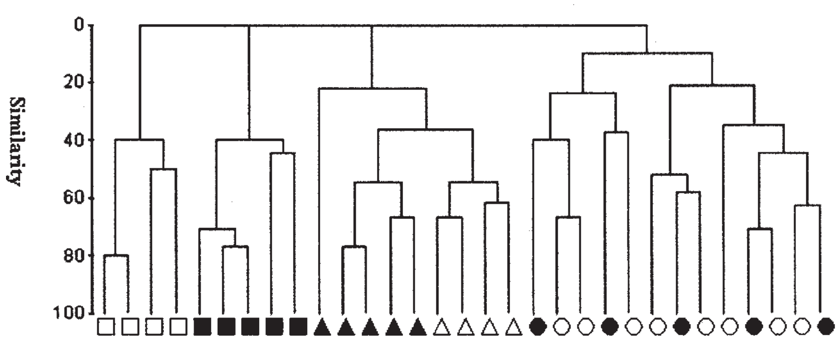


Fig. 6. Cluster ananlysis showing variation in floristics within stands of *Pultenaea glabra* (closed symbols), and adjacent to stands (open symbols) at Lederderg (■), Bunyip (▲), Kinglake (●).

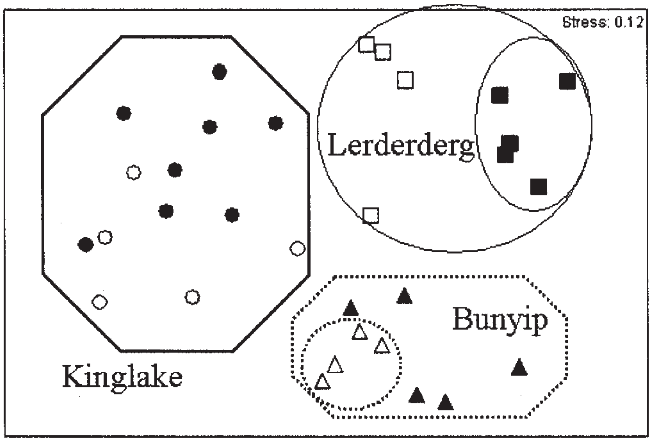


Fig. 7. MDS plot of the floristics within stands of *Pultenaea glabra* (closed symbols), and adjacent to stands (open symbols) at Lerderderg (■), Bunyip (▲), Kinglake (●).

Table 2. Comparison of soil characteristics for three populations of *Pultenaea glabra.* Soil compaction is given within and adjacent to the populations. Compaction means (±S.E.) followed by the same superscript letter are not significantly different at p=0.05.

Variable	Lerderderg	Bunyip	Kinglake
soil texture			
10 cm	silty clay loam	loam	loam
50 cm	medium clay	silty loam	clay loam
pH			
10 cm	4.5	4.7	5
50 cm	6	6	6
colour			
10 cm	2.5Y 6/3	7.5YR 4/1	2.5YR 7/2
50 cm	10YR 5/6	10YR 5/5	10YR 7/6
compaction (kg/cm^2)			
within	0.7±0.1[a]	0.5±0[a]	2.4±0.2[c]
adjacent	1.6±0.2[b]	0.5±0[a]	2.4±0.2[c]

Discussion

Understanding the causes of species persistence at a site, particularly for rare species, is an essential element in their sound ecological management (Keith 2002). Lack of seed, seed size and burial depth, absence of episodic events such as fire which stimulate germination, very specific soil temperatures for germination, physical disturbances, grazing, and limited habitat, have all been proposed as possible contributing factors to natural species rarity (Prober & Austin 1990, Lynch et al. 1999, Lynch 1999, Brown et al. 2003). Lack of specific disturbance, especially lack of fire (Bowkett & Kirkpatrick 2003), may result in local population decline and possibly local extinction.

In Victoria, *Pultenaea glabra* is associated with acidic, seasonally waterlogged soils, swampy areas and drainage lines. This habitat type does not appear to be limited, and like *Pultenaea selaginoides* in Tasmania (Lynch 1999), the restricted distribution of *Pultenaea glabra* in Victoria is unlikely to be due to restricted habitat. Although there was some floristic separation of *Pultenaea glabra* sites from those lacking *Pultenaea glabra*, soil parameters show few differences and did not appear to be associated with the species presence or absence.

The regeneration of many native legume species is promoted by fire (Auld & O'Connell 1991, Williams et al. 2003). Following the mass post-fire regeneration at Lerderderg (Kemp 1985), it was assumed (McMahon & Stuwe 1982, Beardsell n.d, Scarlett & Parsons 1993) that *Pultenaea glabra* was dependent on fire to stimulate germination and the germination response of seeds recovered from the soil seed bank in this investigation is consistent with it being hard-seeded. Heat treatment stimulated rapid onset of germination, and final germination percentages for the three populations (77% to 100%) were consistent with other *Pultenaea* species (Auld & O'Connell 1991, Lynch 1999). The Bunyip and Lerderderg populations had a similar proportion of non-dormant seed (20%) which agrees well with 16.4% reported by Auld & O'Connell (1991). However, the proportion of non-dormant seed was significantly higher (56%) for the Kinglake population. The non-dormant seed fraction reported for other *Pultenaea* species averaged 19.2%, with only one population of one species (*Pultenaea polifolia*) recording 58.9% (Auld & O'Connell 1991, Lynch 1999). Morrison et al. (1992) recorded germination in *Pultenaea glabra* which was not related to fire breaking seed dormancy, but to the high non-dormant proportion of soil-stored seed. They also noted that seed dormancy in *Pultenaea glabra* decreased over time, and suggested that local species persistence depends on the balance between seed loss and successful seedling establishment (Morrison et al. 1992).

The ongoing background germination of the non-dormant seed fraction may explain why the population structures at Bunyip and Lerderderg (Fig. 4) did not conform to that expected of a post-fire obligate seed regenerator. Population structure of species with this regeneration strategy can be expected to show peaks of recruitment coinciding with a regeneration event such as fire, with little recruitment in the inter-fire period (Bowkett & Kirkpatrick 2003).

The Bunyip and Lerderderg populations appear to be multi-aged rather than containing even-aged cohorts related to a dormancy-breaking germination event. Fire may stimulate mass germination and seedling establishment, but the ongoing germination of non-dormant seeds recruits seedlings into the population in the inter-fire interval. This suggests that fire or disturbance is not an obligate requirement for maintaining *Pultenaea glabra* populations. As long as the plants are healthy, flowering, producing seed, and successfully recruiting small numbers of new individuals, the population will persist.

All three populations were last burnt in the early 1980s, and Bunyip and Lerderderg have maintained healthy adult populations over similar time frames without subsequent burning. Since 1981, there has been no fire at Kinglake to stimulate germination, yet large numbers of seedlings <30 cm tall were recorded. This suggests that lack of fire may not be the main cause of the decline in the species at Kinglake.

The seedlings either result from germination of the unusually high proportion of non-dormant seeds, or from patchy mechanical disturbance to the soil which may stimulate germination by abrasion of the seed coat, or both. Mechanical soil disturbance is known to enhance the germination of *Pultenaea selaginoides* in Tasmania (Lynch 1999), and the mosaic of patches approximately 10 m^2 created by the foraging activity of wombats (*Vombatus ursinus*) at Kinglake may contribute to the high numbers of seedlings.

Feral deer numbers increased during the mid-1990s in many areas (including Kinglake), and they can have a significant impact on vegetation structure and floristics (Moriarty et al. 2001, Moriarty 2004). Browsing by feral goats and deer (T. Fitzgerald, Ranger Kinglake National Park, pers. comm.) has been suggested as a possible contributor to the lack of mature plants, and the small increase in secondary and tertiary branch formation at Kinglake also supports the suggestion that seedlings may be browsed by herbivores (Clunie & Becker 1991). Deer are now widespread in Australia (Moriarty 2004) and occur in the Park. Browsing by deer may explain why no dead stems of *Pultenaea glabra* could be found in 2001.

The lack of fire related disturbance since 1981 may also have resulted in floristic changes and increased cover of other plant species. Floristic sampling showed that a thick ground cover of grasses and sedges such as *Gahnia radula* dominates the Kinglake site. Beardsell (n.d.) noted that regeneration of *Pultenaea glabra* amongst the grasses and sedges at Kinglake was very low, and seedlings may not be able to establish in the thick ground layer. Lynch (1999) reported that healthier *Pultenaea selaginoides* populations occurred in more open areas where competition was reduced. Although large numbers of small seedlings were recorded at Kinglake, competition may be a significant factor now preventing the establishment of mature *Pultenaea glabra* at Kinglake National Park.

The future application of fire at Kinglake carries a high ecological risk. Managing *Pultenaea glabra* at Kinglake may require the management of multiple factors, and simply re-introducing fire to the site at this stage may jeopardize survival of existing seedlings and result in local extinction. Burning the site may reduce potential competition from the sedge understorey and stimulate further seed germination, but it will also destroy the large number of seedlings already present. The low soil seed density in the 0–2 cm soil layer at Kinglake compared with the other two populations, may also indicate that many seeds from this soil layer have already germinated and that the seed bank may already be depleted. If the original population decline was influenced by browsing by deer, goats or macropods, and grazing pressures remain high, there is a possibility of local extinction if soil-stored seed is depleted, and establishing seedlings are unable to mature and set seed, to replenish the seed bank. Control of post-fire grazing pressure will need to be a major component of any management option (Meers & Adams 2003), but temporary fencing of the site to allow plants to reach maturity and replenish the seed bank in the absence of fire, may be a less risky option.

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