Seed dynamics of the invasive geophyte *Lachenalia reflexa* Thunb. in south-west Australia

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Summary

Geophytes from South Africa's Cape Province are a particularly serious group of invasive plants in south-west Australia. They threaten natural biodiversity across the region, invading relatively undisturbed habitat and displacing native plant communities. Their success as invaders has been linked to rapid and profuse seedling germination, however studies on a number of species have documented short lived soil seed banks. This study investigates seed viability and soil seed bank persistence of the Cape geophyte, *Lachenalia reflexa* Thunb. where it is invading *Banksia* woodlands on the Swan Coastal Plain, Western Australia.

Seed was collected from naturalized populations in the summer of 2004/2005 and placed in nylon mesh bags buried at two different soil depths, in replicated plots across field sites (February 2005). Samples were retrieved and assessed in May, July and September 2005, September 2006 and September 2007.

Initial tests found 95% seed viability. More than 90% germinated or rotted in the first autumn/winter. No viable seed remained at the 10 cm depth by September 2006 or at the 1 cm depth by September 2007. The results show that *L. reflexa* seed have high initial viability but do not persist in the soil seed bank for more than three years.

Keywords: Invasive, geophyte, germination, viability, soil seed bank, *Lachenalia reflexa*.

Introduction

A detailed understanding of the biology of invasive plant species underpins effective weed management strategies (Hobbs and Humphries 1995, Mortensen *et al*. 2000). Knowledge of seed biology in particular provides an understanding of patterns in recruitment of an invasive species and the potential persistence of populations over time.

With the capacity to invade undisturbed bushland and form dense monocultures, South African geophytes are a particularly serious group of invasive plants in south-west Australia. A total of 53 species have been recorded as naturalized (Keighery and Longman 2004). Protection and restoration of remnant vegetation across the region often requires an understanding of how to manage invasive geophytes.

Lachenalia, in the family Asparagaceae, is a genus of around 120 species of winter growing geophytes endemic to South Africa and Namibia (Duncan *et al.* 2005). Native to the Cape Floristic Region, *Lachenalia reflexa* (yellow soldier) was first recorded as naturalized in south-west Australia in 1938 (Western Australian Herbarium 1998–2010). It is now a serious weed of *Banksia*/*Eucalyptus* woodlands on the western side of the Swan Coastal Plain and has recently been the target of a regional weed strategy in south-west Australia (Bettink 2009). With a single annually renewed bulb, *L. reflexa* disperses into bushland mainly by small (2 mm) shiny black seed that have a tiny arilode. Papery capsules contain 60–100 seed and there are up to 10 capsules per plant. Seed is released in late spring or summer and appears to disperse via water into bushland following autumn rain.

Although appropriate control methods are well documented (Brown *et al.* 2002, Brown and Brooks 2003) there is little known about ecology or reproductive biology where *L. reflexa* is invading native plant communities. In particular, seed viability, patterns of seedling emergence and persistence of naturalized populations in the soil seed bank are not well understood. This information is critical for understanding how to manage invading populations over time including the length of any control program.

There are few detailed studies on the seed ecology of individual species of geophytes where they occur naturally in South Africa. However it is generally assumed that seed of many geophytes are not persistent in the soil seed bank (Manning *et al.* 2002, Keeley *et al.* 2006). There is also evidence that for some species seedling recruitment and population expansion occurs in a small window following fire (Le Maitre and Brown 1992, Keeley and Bond 1997).

The objective of this study was to investigate the seed biology of *L. reflexa* and gain an understanding how to manage populations where they are invading native plant communities. Specifically, we investigated seed viability and persistence in the soil seed bank of *L. reflexa*.

Methods

Study area and seed burial site

The site chosen for the burial of *L. reflexa* seed was on the Swan Coastal Plain in Woodvale Nature Reserve (31°47'03"S, 115°46'55"E), within close proximity to the city of Perth, Western Australia. The disturbed *Banksia attenuata*, *Eucalyptus* woodland on the Spearwood Dune System of the reserve are species rich, (average of 55.2 species in a 10 × 10 m quadrat) with an understorey of shrubs, herbs, sedges and grasses (Gibson *et al.* 1994). Dense populations of *L. reflexa* were present in the understorey of the woodlands at the seed burial site.

Initial seed viability

Seed was collected at Woodvale Nature Reserve from mature fruits of approximately 200 plants scattered through naturalized populations of *L. reflexa* in November 2004.

Initial seed viability was determined in germination tests carried out in January 2005. Five replicates of 25 seed were placed on agar (0.75%) and placed in growth cabinets at 15°C with a 12 hour photo period. Seeds that did not germinate after 10 weeks were assessed for viability using a cut test. Seeds were scored as viable if a firm, white, moist endosperm was present (Ooi *et al.* 2004).

Soil seed bank persistence

Seed was placed in 15 × 20 cm nylon mesh bags containing 200 g sterile sand to keep individual seed separated, and buried in February 2005 in five plots placed across naturalized populations of *L. reflexa*. In each plot 20 bags were buried, each bag containing 500 seeds. Ten bags were buried in the top 1 cm of soil and ten bags were buried at 10 cm. These depths were chosen to reflect natural seed burial depths following dispersal with 1 cm representing superficial surface burial versus burial resulting from substantial soil disturbance (10 cm). Chicken wire was secured over each plot to protect the site from rabbit and bandicoot diggings. The soils across the site were uniform grey to orange light sand.

One bag per soil depth was recovered from each plot in May, July and September of 2005, September 2006 and September 2007. Seeds recovered in May and July were scored as either potentially viable if they were firm and intact or as germinated/rotted if they were not. It was not possible to separate germinated from rotted seed. Following retrieval in September 2005, 2006 and 2007, seed that were still intact were assessed for viability in growth cabinets at 15°C with a 12 hour photo period. Seed that did not germinate after 10 weeks were assessed using a cut test and were scored as viable if a firm, white, moist endosperm was present.

Results

Initial germination tests indicated seed was 95.2% viable with all germination occurring within 18 days.

Of the seed buried at 1 cm, 18.8% (±1.3) were still viable when retrieved in May 2005 and 8.74% (±3.8) were still viable in July. By September 2005, 3.3% (±1.5) remained viable. In September 2006 1.3% (±1.1) remained viable and by September 2007 no seed of *L. reflexa* buried at 1 cm remained viable.

Of the seed buried in the field in February 2005 at 10 cm, 5.96% (±1.9) were still viable when retrieved in May and 0.24% (±0.2) were still viable in July. By September 2005, 0.04% (±0.4) was still viable. By September 2006 bags buried at 10 cm contained no viable seed (Figure 1).

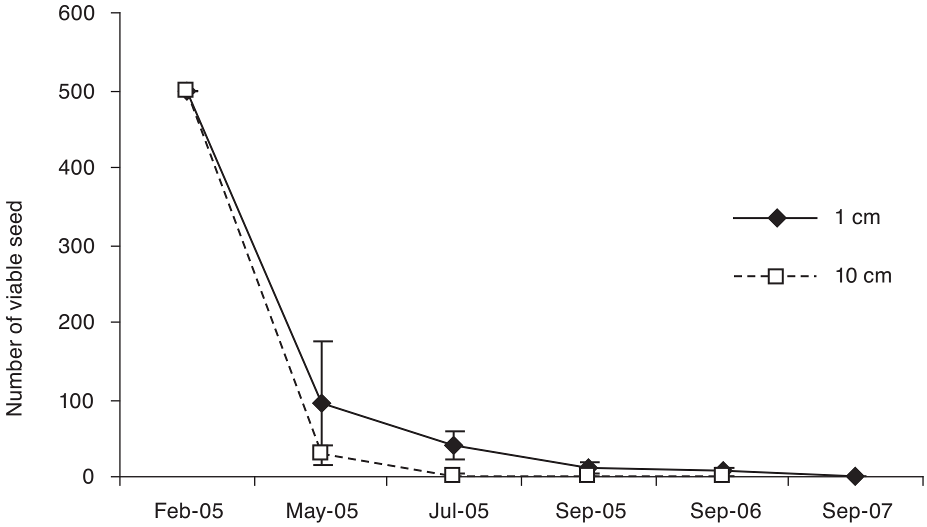

Figure 1. Number of seed that remained viable buried at 1 cm and 10 cm over three years.

Discussion

The results of our study indicate that the seed from naturalized populations of *L. reflexa* has high viability (95.2%) with germination occurring relatively rapidly, all within 18 days, under controlled conditions. With more than 80% of seed germinating/rotting within three months of burial (May 2005) in the field, indications are that germination also occurs relatively rapidly under field conditions. The pattern of high viability and rapid germination is similar to two other invasive geophytes in south-west Australia, *Freesia alba* × *leichtlinii* (Iridaceae) and *Sparaxis bulbifera* (Iridaceae) (Brown and Paczkowska 2008). These results also support those of van Kleunen and Johnson (2007) that South African geophytes naturalized outside their native range tend to have rapid and profuse seedling germination.

After seven months of burial, at the end of the first growing season (spring 2005) almost all the seed had germinated or rotted. After 14 months (spring 2006) no viable seed of *L. reflexa* remained at 10 cm and after 21 months (spring 2007) no viable seed remained at 1 cm. While *L. reflexa* does not form a persistent soil seed bank, its seed persists longer in the soil than two other South African geophytes that are invasive in south-west Western Australia, *Freesia alba* × *leichtlinii* and *Sparaxis bulbifera*. The seed of both these species was found to persist for just one season (Brown and Paczkowska 2008). The lack of a persistent soil seed bank in these three invasive geophytes supports evidence from their native range of Cape Floristic Region, that geophytes typically possess non-dormant seeds (Keeley and Bond 1997, Manning *et al*. 2002). It is also consistent with findings of studies on soil seed bank persistence of native geophytes of the Californian chaparral (Keeley 1994, Tyler and Borchert 2002, Keeley *et al*. 2006).

While seed plays a crucial role in the recruitment of individuals and expansion of populations, the persistence of populations over time depends on the annually renewed bulbs of *L. reflexa*. While carefully targeted, selective herbicide application over one or two years will result in effective control of bulbs (Brown *et al*. 2002, Brown and Brooks 2003), the results of this research shows managers will need to survey and control germinating seedlings for at least three years.

A non-persistent seed bank implies limited opportunities for seedling recruitment. Where they occur in Mediterranean ecosystems geophytes often flower particularly prolifically following fire. This is often followed by seedling recruitment in the second year following fire (Kruger 1983, Le Maitre and Brown 1992, Keeley *et al*. 2006, Borchert and Tyler 2009). The prolific amount of seed produced is able to germinate and establish particularly well in the post fire environment. The second growing season following a summer fire, when seed produced from post fire flowering would germinate, could be a crucial time to control *L. reflexa* and prevent expansion of existing populations.

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Economic and environmental assessment of the performance of reduced rates of two post-emergence herbicides in an arid irrigated production system of central Australia: a pilot study

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Summary

The use of herbicides can add considerable costs to production practices on marginal land, and increase risks to environmental and human health. The relative performance of label and sub-label rates of the post-emergence herbicides (Amitrole T and Basta) and label rates of Roundup was compared within a benefit-cost analysis framework, in an arid irrigated production system in central Australia. Sub-label rates of Amitrole T and Basta were as effective at weed suppression as their label rates (LR); approximately 50% reduction in weed cover was recorded across the trial with both label and sub-label rates for both herbicides. The sub-label rates of Amitrole T (75% LR and 65% LR) and Basta (75% LR) had a statistically similar economic benefit-cost ratio as their corresponding LRs, and the LR of Roundup. The equivalence of Basta's sub-label rate in terms of economic efficiency is even more noteworthy if one takes into account that significantly lower amounts of the herbicide needed to be applied to achieve the level of weed suppression obtained using the label rate of Roundup. Our results suggest ways to improve the economic and environmental efficiencies of herbicide use in the arid, irrigated production systems of central Australia.

Keywords: Sub-label rates, buffel grass, arid-zone weeds, cost-benefit analysis, sustainability.

Introduction

The global trend in farming practices since the 1950s is one that is increasingly reliant on intensive and extensive chemical-inputs in the form of fertilizers, and pesticides (Matson *et al.* 1997, Tilman *et al.* 2002). Productivity in Australian agriculture mirrors global trends, increasing by nearly 250% over the past half a century, a fact at least partly attributable to reliance on chemically intensive farming (Llewellyn *et al.* 2002, Radcliffe 2002). Agriculture currently occupies approximately 54% of the total Australian land area, contributing nearly $43.27 billion per annum to the economy (ABS 2009a,b). The cost of non-fertilizer chemical inputs (e.g. pesticides, soil amendments) totalled nearly $3 billion for the period 2006–2007 (ABS 2008). While such agricultural activity has successfully increased yields of food crops this productivity has come at an environmental (e.g. impact on ecosystem services, pollution) and social cost (e.g. health risks to rural communities from chemical use), raising concerns about continuing such an approach unchecked into the future (Bellamy and Johnson 2000, Matson *et al.* 1997, Tilman *et al.* 2002).

Reducing the reliance on non-fertilizer chemical inputs by agriculture is not only environmentally beneficial, but is also economically prudent. For example, the cost of herbicide use for 2006–2007 in Australian agriculture was nearly $980 million (ABS 2008). However, numerous studies have shown that the optimal rates of application of herbicides vary in relation to environmental context (Bostrom and Fogelfors 2002) and that in many instances the required application rate of such chemical interventions are below that recommended by chemical manufacturers (Zhang *et al.* 2000). Identification of the level of chemical intervention for a given production context can therefore result in chemical use that is both effective at achieving the economic objective, and reducing risks to the environment.

Primary production in central Australia is limited by aridity, nutrient-poor soils, and remoteness that restricts access to markets and labour; however, the availability of aquifer resources (albeit of variable quality) makes sustainable irrigated agriculture feasible (Slatyer 1961). While the inherent productivity of soils may make chemical control of weeds economically viable in high quality agricultural lands, the use of herbicides is often a significant production cost in marginal, irrigation-reliant, arid-zone production systems of central Australia, and is typically only viable in high-value crops (Ellis *et al.* 2010, Faroda *et al.* 2007, Heong *et al.* 1995). As in other arid locations, weeds