# Seed dynamics of the invasive geophyte *Lilium formosanum* on Lord Howe Island – lots of seeds but they don't live long

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**Summary** The success of many plants as invaders has been linked to their high seed production, high seed viability, efficient dispersal and persistent seed banks. This paper describes the results of a study of the seed production, seed viability and germination of the invasive geophyte *Lilium formosanum* on Lord Howe Island. Seed production and levels of seed viability are high but the soil seed bank is transient. Management of this species should focus on curtailing seed production and removing established plants rather than extinguishing the seed bank.

**Keywords** Geophyte, *Lilium formosanum*, seed production, seed viability, seed bank.

## INTRODUCTION

Invasive plants pose a significant threat to the conservation values of islands (Timmins and Braithwaite 2002), many of which have histories of high extinction rates (Frankham 1998). *Lilium formosanum* A.Wallace (Liliaceae) (Taiwan lily) is naturalised and widespread in native ecosystems on the ecologically significant Lord Howe Island (Warner *et al.* 2006). There have been few studies of Taiwan lily as a weed and currently there are no effective methods for controlling this species.

The development of effective weed management plans should be based on sound information on the ecology of both the invasive species and the invaded ecosystem (Edwards 1998, Hobbs and Humphries 1995, Mortensen *et al.* 2000). Seed ecology is an important consideration here because seed banks enable re-establishment following control of established plants (Hesse *et al.* 2007, Rahman *et al.* 2001).

Taiwan lily is a fast-growing, bulbous, perennial, geophyte that shows broad environmental tolerances (Hiramatsu *et al.* 2002). The capsular fruits contain up to 1500 light, winged seeds that are readily dispersed by wind. Along with apparent high seed production, these dispersal traits may contribute to its invasiveness. However, for Taiwan lily there is little quantitative information available on seed population dynamics.

The two main features contributing to the plant's dispersal and persistence are the seed bank and 'bulb bank'. As no studies have yet considered which feature plays the most important role there is a need to carry out basic ecological studies on this plant to help focus management actions.

This paper describes and quantifies seed production, seed viability and longevity of seed in the soil seed bank at both the plant and population levels. It discusses the importance of these factors in the success of this particular weed on Lord Howe Island, Australia.

## MATERIALS AND METHODS

**Study area** Lord Howe Island has an area of 16 km$^2$ and is located 720 km east of the New South Wales coast. It is an oceanic island with a sub-tropical climate and altitudes up to 877 m. It is a World Heritage listed area with high levels of endemism (e.g. 103 out of 240 vascular plants are endemic) and many unique communities (Warner *et al.* 2006). Taiwan lily occurs in most vegetation types on the island from sea level to 700 m.

**Sampling** Ten sites were selected across the island, representing the range of vegetation types and altitudes in which the weed is found. Infestations of Taiwan lily were sampled at each site using four randomly located 1 × 1 m quadrats. The height and stem basal diameter of all plants were measured in January, March and October from 2005–2007. The numbers of flowers and seed capsules on each plant were recorded in January and March, respectively, each year. Between-site variability is not discussed in this paper.

**Seed collection and assessment** Across the 10 sites, mesh bags were placed over green capsules on 88 plants in March 2006. Their contents were collected and dried after capsules had dehisced in May 2006. Measurements were taken of plant height, shoot diameter, capsule length and number of capsules per plant. Seeds from each capsule were visually classified on a light table as 'normal and embryo present', 'no visible embryo' or 'distorted'. They were counted and weighed.

Germination tests on the three classes of seeds were carried out using seeds from two capsules from each of the 10 collection sites. Seeds were germinated in a growth cabinet at a constant 15°C, consistent with the methods used by Carpenter and Ostmark (1990). Seeds were checked daily for germination, as defined by the emergence of the radicle from the testa (Hiramatsu *et al.* 2004). These data were used to estimate total seed production and viable seed production per plant and per unit area.

**Seed longevity in the soil seed bank** Ninety-six mesh bags, each containing 50 seeds, were buried at one of two depths, either just below leaf litter or at 2 cm below the mineral soil surface in each of two major soil types present on the island, basalt and calcaranite. Bags were exhumed after 3, 5 and 10 months, by which time the number of seeds remaining viable had dropped below 0.02%. All remaining ungerminated seeds were assessed for germinability in a growth cabinet at a constant 15°C and were deemed inviable if they were rotted and had not germinated after six weeks. Data were analysed by performing a 3-way ANOVA on arcsine transformed data, with the main factors as depth, time and soil type.

Seeds from each site were also tested in the laboratory using an accelerated ageing test (Long *et al.* 2007). Seeds were placed in open glass vials over a 47% relative humidity lithium chloride (LiCl) solution (37 g 100 $mL^{-1}$ deionised $H_2O$) within a sealed box at 20°C, for 14 days. They were then transferred to a second box at 60% RH (30 g LiCl 100 $mL^{-1}$ $H_2O$) at 45°C. Vials were removed daily and seeds were placed on agar plates for standard germination testing.

## RESULTS

**Seed production and viability** Of the seeds removed from capsules 88.5% had an apparently normal embryo, 9.5% had no visible embryo and 2.0% were distorted. The mean viability of each seed class was 96.8%, 0% and 77.3%, for 'embryo present', 'no visible embryo' and 'distorted' seeds, respectively (Figure 1).

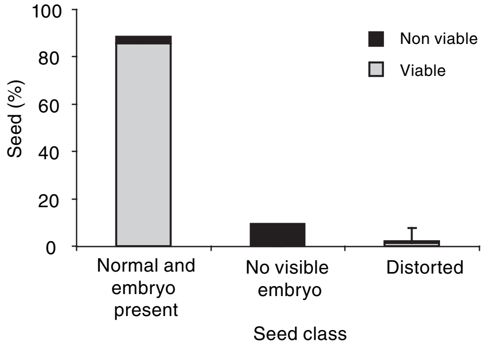


**Figure 1.** The mean percentages (±SE) of viable and non-viable seed of three different seed classes (normal and embryo present, no visible embryo, and distorted) from seed capsules of Taiwan lily.

The mean (±SE) number of seeds per capsule was 913 (±39, $n$ = 88), with a mean of 2.6 (±0.2, $n$ = 88) capsules per plant and 5.4 (±0.6, $n$ = 40) plants $m^{-2}$. These figures yield annual seed production estimates of 2374 and 12,685 per plant and $m^{-2}$, respectively.

**Seed longevity in the soil seed bank** A 3-way ANOVA revealed that duration of burial (P = 0.158) and soil type (P = 1.000) were not significant, but burial depth was significant (P = 0.041). By three months, seed bags buried below the litter contained no viable seed. However, the percentages of seeds buried at 2 cm that were viable at three months and 10 months were 0.06% (±0.002) and 0.02% (±0.001), respectively, with nil viable seed present at the 5-month exhumation.

In the accelerated ageing test, viability had fallen to below 50% within 1.8 (±5.4) days. This puts the seed into a transient seed bank category, having a maximum survival rate after 20 days of 50% (Long 2007).

## DISCUSSION

The nature of seed production is important in the management of any weedy species. Taiwan lily produces large numbers of seeds per capsule, per plant and per unit area. Seed banks are transient. Seeds that do not germinate rapidly decay in the leaf litter and sub-soil environments. Viability of fresh seeds is high, but under typical field conditions the majority of these germinate within three months, leaving less than 0.02% of viable seed in the seed bank. The accelerated ageing test suggested seed that does not germinate within one year is non-viable.

Wind-dispersed seeds are probably responsible for most of the long-distance dispersal of naturalised populations of this species, leading to the establishment of new infestations. However, persistence of infestations relies on a 'bulb bank' rather than a seed bank. Management of this species must take this into account (S. Warner unpubl. data).

Reducing seed production would minimise the risk of establishment of new infestations. The soil seed bank could be eliminated by preventing seed production for a single season. This could be done by complete removal of all shoots prior to seed production (Warner and Grice 2007). However this would need to occur every year. Reducing the 'bulb bank' presents a much greater challenge.

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