**Ecology of Lilium formosanum Wallace and implications for management**

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**Summary**  Lord Howe Island (LHI) is a World Heritage listed area with 240 species of indigenous vascular plants, high levels of endemism and many unique habitats. In 1984, 173 exotic plant species were listed on LHI and today there are at least 218. One of these species, Formosa lily (*Lilium formosanum* Wallace), poses a threat to the flora and fauna of LHI. Formosa lily is an herbaceous perennial that survives over winter as an underground bulb. It is fast growing with high morphological and physiological plasticity. Plants are self-fertile and prolific seeders with efficient dispersal. In its native range, Taiwan, Formosa lily tends to grow in areas with anthropogenic and natural disturbances, situations that are common in some Australian environments. On LHI, Formosa lily is commonly found in light gaps in otherwise closed forest. It also occurs in more open cliff and ledge communities. These habitats support a number of rare or threatened endemic species, so it is possible that it competes with these plants for resources. My current research program is focusing on key aspects of the species’ ecology, population biology and the factors governing its distribution, abundance and impacts, as a basis for effective management. Our experiments are quantifying important processes in the lifecycle, responses to environmental variables, some aspects of impact on native species richness and responses to physical damage.

**Keywords**  *Lilium formosanum*, Formosa lily, geophyte, Lord Howe Island.

**INTRODUCTION**

LHI is an oceanic island with a sub-tropical climate, and altitudes up to 877 m in the southern mountains. It is World Heritage listed with high levels of endemism and many unique habitats (Lord Howe Island Board 2004). LHI sustains 240 species of indigenous vascular plants, of which 103 are endemic (Lord Howe Island Board 2002). This high proportion of endemic species was one of the factors used to support the case for World Heritage listing in 1982 (Hutton 1986).

In 1984, 173 exotic plant species were listed for LHI (Pickard 1984). Today there are over 218 exotic plant species present (Lord Howe Island Board 2002). Analysis of historical exotic plant records has shown that the invasion of species has occurred continually since the island was discovered in 1788, and naturalisations have occurred at an average rate of 1.3 species per year (Pickard 1984).

These exotic species have the ability to alter the plant and animal communities of LHI. Of the 218 exotic species, six are of major concern as environmental weeds: cherry guava (*Psidium cattleianum* Sabine var. *cattleianum*), ochna (*Ochna serrulata* (Hochst.) Walp.), Crofton weed (*Ageratina adenophora* (Spreng.) R.M.King & H.Rob), bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.), ground asparagus (*Asparagus aethiopicus* L.) and Formosa lily. These weeds pose a serious threat to the island’s native vegetation.

This paper describes a project that is focusing on Formosa lily, examining key aspects of the species’ ecology, population biology and the factors governing its distribution, abundance and impacts, as a basis for effective management. Our experiments are quantifying important processes in the lifecycle, responses to environmental variables, some aspects of impact on native species richness and responses to physical damage.

**FORMOSA LILY, A BULBOUS PERENNIAL GEOPHYTE**

Formosa lily is a bulbous perennial geophyte with many features that contribute to its success as a weed and coloniser. It shows broad environmental tolerances and is well-adapted to a wide range of conditions. It has rapid growth from germination to flowering (Hiramatsu et al. 2000b), enabling it to compete with other plant species. Formosa lily produces a large number of light weight winged seeds, which are easily dispersed by wind. An underground bulb enables it to survive during the unfavourable conditions of winter, and provides stored reserves that are mobilised in the spring to promote spring growth. Unfortunately there are major knowledge gaps in the weed’s ecology and biology which makes it difficult to know what impacts it has, how serious they might be, and how to plan and implement successful control.
On LHI, Formosa lily has a perennial lifecycle where vegetative growth begins in July–August, flowering occurs in January–February, seeding in April and then the shoot dies off and the plant winters as an underground bulb. The high photosynthetic rate of the leaves builds up reserves, which are stored in the bulb and are suspected to facilitate rapid growth from seed-sowing to reproductive age (Hiramatsu et al. 2000b). The bulb enables it to escape adverse climatic conditions and helps it avoid competition from other herbaceous vegetation. Formosa lily does not do well under strong competition, but it can survive as an underground bulb and re-emerge by drawing on stored reserves. Shii (1983) noted that, when faced with strong competition from grasses and vines, it can stay dormant underground for several years until competition has subsided when it will rapidly re-emerge. This survival strategy in the face of short-term habitat stresses could be exploited by revegetating areas that have been infested by Formosa lily and maintaining a vigorous ground cover of other species to prevent re-emergence (Shii 1983).

A high degree of self-fertilisation has been reported (Inagaki 2002, Shii 1983, Rambuda and Johnson 2004) whereby plants produced from self-pollination displayed no inbreeding depression, better growth, more shoots, higher resource allocation to bulbs and a longer flowering season, compared with cross-pollination.

A high annual net production and an early shift to the reproductive phase, is likely to be advantageous for establishment in disturbed or competitive environments (Hiramatsu et al. 2000b). Flexible stems enable it to grow in areas with high winds and light weight seeds aid wind dispersal (Shii 1983).

DISTRIBUTION AND HABITATS
This plant has an ability to adapt to a broad range of conditions and take advantage of natural and anthropogenic disturbances in both its native and naturalised range. Its native range is restricted to Taiwan where it grows from sea level to 3500 m (Liu and Ying 1978). In its native range it is often found growing in disturbed fields amongst tall grasses, on bare cliff walls prone to landslips and grassy highlands disturbed by strong winds above the forest limit (Hiramatsu et al. 2000a). It occurs naturally in areas where natural disturbances have occurred. Examples include tall grass fields on arable lands, forest margins and poorly vegetated steep rocky cliffs (Hiramatsu et al. 2001).

Formosa lily is naturalised in New Zealand, Norfolk Island, Australia, South America (Randall 2002), Japan (Inagaki 2002) and South Africa (Walters 1983), where it is found extensively in disturbed areas dominated by relatively tall grasses, as in its native habitat (Hiramatsu et al. 2000a). Formosa lily was introduced to Australia as an ornamental species, but is now invasive in many coastal and inland regions of Victoria, Queensland (Toowoomba and Maleny), New South Wales (including Blue Mountains and New England area) and LHI (Csurhes and Edwards 1998).

In the early 1980s, Formosa lily was described by Pickard (1983) as firmly established in the southern mountains of LHI. Today it is distributed throughout most vegetation types from the south to the north of the island. It is found across an altitudinal range from sea level up to 700 m and on the two major soil types found on the island, Calcaranite and Basalt.

On LHI, Formosa lily is commonly found in light gaps in closed forests of Drypetes deplanchei subsp. affinis (Pax & K.Hoffm.) P.S.Greene–Cryptocarya triplinervis R.Br. including the exposed variant of that community (Pickard 1983), in megaphyllous broad sclerophyll forest consisting of Howeas forsteriana (C.Moore & F.Muell.) Becc. with canopy gaps, on dunes amongst Spinifex sericeus R.Br. and in ledge/cliff communities. The ledge/cliff communities contain many rare endemic plant species, including Carmichaelia exsul F.Muell., which is only found in ledge communities above 400 m altitude (Orchard 1994).

RESEARCH PROGRAM
Knowledge of basic biology, ecology and population dynamics of a weed provides an important basis for the development of effective management strategies (Campbell and Grice 2000). Life-cycle traits are crucial to the success of the invading species (Dietz et al. 1999) and by understanding these we can begin to understand population establishment and spread. Some important traits include rapid initial growth and sequestration of resources, high morphological and physiological growth plasticity and efficient seed dispersal (Dietz et al. 1999).

Work initiated in 2005 is focusing on critical aspects of the ecology of Formosa lily on LHI. A phenological study is quantifying the seasonal cycle of growth, flowering and seed production across a range of habitats on LHI. The vegetation associations of the species are being documented, along with the environmental variables that drive those associations. For example, light gaps in the forest canopy appear to facilitate the occurrence of Formosa lily and it commonly co-occurs with native Carex spp.

Work on seed dispersal will give an indication of the ability of the species to colonise new areas (Willson and Traveset 2000). Additional studies will quantify seedbank size and seed longevity. This information is...
important as it indicates the likelihood of re-infestation from soil-stored seeds following control operations.

Other work will examine how temperature, light, depth of burial and water availability influence germination and emergence. This will be important in identifying the weed’s survival strategies (Benvenuti et al. 2004).

Formosa lily has a tendency to grow along paths on LHI, where plants are often snapped or pulled up by tourists and locals, a practice perceived as contributing to control. An experiment has been established to test the usefulness of this practice. In particular it will determine whether it retards growth or reduces seed production. At present it appears that removal of the shoot tip is the most effective method. Partial or complete removal of the stem enables the lily to produce another shoot. A glasshouse experiment is examining the reproductive capacity of Formosa lily from bulb scales. This will determine the capacity of the species to spread by this means. Scales of different sizes have been removed from bulbs and planted at various depths, and plant growth recorded over a five month period.

Finally, Formosa lily grows in areas where rare or threatened endemic species are present and has the potential to compete with them for space, light and/or nutrients. Information on the areas in which Formosa lily invades and its habitat preferences will indicate those species and habitats most at risk from its invasion.

**IMPLICATIONS**

Devising effective weed management strategies requires knowledge of the plant’s ecology and its impact on the surrounding environment. In natural habitats there are major challenges in attempting to quantify the environmental impact of invasive species and the outcomes of such studies are sometimes ambiguous (Eser 1998). However, it is important to identify and quantify impacts to ensure weed management resources are directed efficiently. For example, perceptions of impact on native species and invaded communities may not be accurate.

Formosa lily apparently has the potential to invade any community on LHI that has light gaps present in the canopy or some form of natural or anthropogenic disturbance that creates light gaps in the canopy. In addition, naturally open communities in which Formosa lily is prevalent include rare or threatened endemic species that may require priority action.

This work will contribute to knowledge of Formosa lily as an invasive species and its weediness and impact on surrounding vegetation. It will enable focus to be placed on its management in areas of greatest concern. The work will also be relevant to other bulbous geophytes, a group of plants that have received little research attention either in Australia or elsewhere.

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