Pest plant risk assessment

Kahili ginger

Hedychium gardnerianum

White ginger

Hedychium coronarium

Yellow ginger

Hedychium flavescens

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The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.

Front cover: Kahili ginger at Springbrook, Queensland

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Summary

Hedychium gardnerianum is a popular garden plant that is widely available in nurseries. However, it is a major pest in Hawaii, New Zealand, the Azores and South Africa. It has the potential to form pure stands within the understorey of upland rainforests and other moist, upland forest habitats in south-east Queensland, especially along forest margins, gaps and other disturbed habitats. Its seeds are readily dispersed by birds. *H. gardnerianum* exists as small, isolated populations in south-east Queensland, with sites at Mount Glorious, Springbrook and Mount Tamborine. It appears vulnerable to successful control, if not eradication. Failure to control this species at an early stage of population development could result in significant damage to upland subtropical and temperate rainforests and other moist, cool forest habitats in high elevation areas of coastal, south-east and perhaps North Queensland.

H. coronarium is also a popular garden plant. It is naturalised in south-east Queensland and in North Queensland. While slow to spread, it has the potential to be as troublesome as *H. gardnerianum*.

H. flavescens is a popular garden plant that has become a major pest in New Zealand and Hawaii. It is not yet reported to be naturalised in Queensland.

Identity and taxonomy

Taxa: *Hedychium gardnerianum*

Common names: Kahili ginger, kahila garland-lilly, yellow ginger lily (Australia and New Zealand), awapuhi kahili (Hawaii), cevuga dromodromo (Fiji), conteira (Spanish-Azores), girlandenblume (German), kahili (Hawaii), kopi (Cook Islands), sinter weitahta (Pohnpei), wild ginger (New Zealand), Mr. Gardner's garland flower (historical) (Porcher 1995).

Kahili (kah-HEE-lee) are feathered standards used from ancient times by Hawaiian royalty. Hawaiian nobility use *kahili* to show status, lineage, and family ties.

Named in honour of Edward Gardner, the British resident at the court of Nepal, Kathmandu.

Taxa: *Hedychium coronarium*

Common names: Sweet scented garland flower (historical), butterfly-ginger, butterfly-lily, cinnamon-jasmine, garland-flower, ginger-lily, white butterfly, white-butterfly ginger, white ginger, white-ginger-lily (Porcher 1995).

Taxa: *Hedychium flavescens*

Synonyms: *Hedychium emeiense* Z.Y. Zhu, *Hedychium panzhuum* Z.Y. Zhu

Common names: Cream garland lily, cream ginger, cream ginger lily, wild ginger, yellow ginger-lily, yellow ginger (Porcher 1995).

Taxonomy: *H. gardnerianum*, *H. flavescens* and *H. coronarium* are members of the family Zingiberaceae. The taxonomy of the *Hedychium* genus is unclear. While at least 115 species names have been described in the published literature, Wood et al. (2000) estimated that only 65 of these are biologically valid species. Interspecific hybrids of *Hedychium* are readily created and natural hybridisation undoubtedly contributes to taxonomic confusion (Wood et al. 2000). The taxonomy of the 'white' and 'yellow' gingers (*H. flavescens* and *H. coronarium*) is particularly confusing. For example, in New Zealand, material described as either 'white ginger' or 'yellow ginger' has been referred to as *H. flavum*, *H. flavescens*, *H. coronarium* or *H. oblongum* in various publications over the past 30 or more years. In 1973, a taxonomist in New Zealand identified material formerly known as *H. flavescens* as *H. coronarium* var. *subitum*.

Expert opinion subsequently changed to *H. flavescens* for what is referred to as 'yellow ginger' (Orchard 1978). However, in South Africa, *H. coronarium* is considered to be a separate species from *H. flavescens* and *H. flavum*, the distinctions possibly based only on flower colour, as described by Henderson (2001); *viz*. *H. coronarium* (white flowers, sometimes yellowish basally), *H. flavescens* (yellow flowers, sometimes reddish-yellow basally, calyx approximately the same length as the corolla tube) and *H. flavum* (yellow flowers, calyx nearly as long as the corolla tube).

DNA analysis by Wood et al. (2000) split *Hedychium* into three groups; each group correlated to a separate climatic zone. The first group comprises high Himalayan species such as *H. spicatum*, *H. gracile*, *H. densiflorum*, *H. ellipticum* and *H. yunnanense*. The second group, the lower altitude Himalayan species, includes *H. coccineum*, *H. coronarium*, *H. flavescens*, *H. gardnerianum, H. stenopetalum*, *H. thyrsiforme* and *H. urophyllum*. The third group consists of tropical epiphytes such as *H. hasseltii*, *H. philippinense* (*H. muluense*), *H. bousigonianum* and *H. cylindricum*.

At least seven species are widely traded as garden ornamentals around the world, namely:

- *H. densiflorum* Wallich (ornamental cultivars include 'Assam orange' and 'Stephen')
- *H. coronarium* (ornamental cultivars include 'Gold spot')
- *H. flavescens*
- *H. gardnerianum* (ornamental cultivars include 'Tara', 'Extendum' and 'Compactum')
- *H. coccineum* Buch.-Ham.(syn. *H. angustifolium*) (red ginger lily, scarlet ginger lily, peach lily)
- *H. spicatum* Smith
- *H. greenei* W.W.Sm. (scarlet ginger, salmon ginger, Himalayan ginger, Bhutan butterfly ginger).

One of the most popular species of *Hedychium* is *H. gardnerianum*, which appears for sale on various internet sites run by commercial nurseries. Ornamental cultivars include cv. 'Tara' which 'produce mildly fragrant orange flowers' (Hawaiian Botanicals 2006).

Description

H. gardnerianum is a herbaceous, perennial plant usually 1–2 m tall (Figure 1). Adult stems are produced annually from large, branching rhizomes (tuberous roots). Beds of living rhizomes can form a dense mat up to 1 m thick. Leaves are alternate, ovate-elliptic, apex acuminate, 20–60 cm long and 8–18 cm wide. Flowers are produced in attractive spikes 12–45 cm long. Each flower is lemon yellow with conspicuous red stamens. Soon after flowering, the mature seed heads have a bright red colour as the seed capsules develop and open. Seeds are bright red, fleshy, 1.5–1.8 cm long (Figure 2).

H. flavescens—Pseudostems 1–2 m. Leaves sessile; leaf sheath slightly pubescent; ligule 3–5 cm, membranous; leaf blade elliptic-lanceolate or lanceolate, 20–50 × 4–10 cm, abaxially pubescent, base attenuate, margin membranous, apex caudate-acuminate.
Spikes oblong, 15–20 × 3–6 cm; bracts imbricate, oblong to ovate, 3–4.5 × 2–4 cm, concave, 4- or 5-flowered; bracteoles tubular, membranous. Flowers yellow or yellow-white, fragrant. Calyx 3.5–4 cm, split on one side, apical margin entire. Corolla tube 7–8.5 cm, slender; lobes linear, 3–3.5 cm. Lateral staminodes wider than corolla lobes. Labellum erect, creamy yellow with an orange patch at base, obcordate, longer than wide, apex 2-lobed. Filament subequaling labellum. Ovary hairy. Stigma funnelform, margin bearded. 2 n = 34 (Shu 2000).

H. coronarium—Pseudostems 1–3 m. Leaves sessile; ligule 2–3 cm, membranous; leaf blade oblong-lanceolate or lanceolate, 20–40 × 4.5–8 cm, adaxially glabrous,
abaxially finely pubescent or thinly hairy, base acute, apex long acuminate. Spikes ellipsoid, 10–20 × 4–8 cm; bracts imbricate, ovate, 4.5–5 × 2.5–4 cm, 2- or 3-flowered. Flowers white, fragrant. Calyx ca. 4 cm, split on one side. Corolla tube ca. 8 cm, slender; lobes lanceolate, ca. 5 cm, central one spatulate, apex mucronate. Lateral staminodes oblong-lanceolate, ca. 5 cm. Labellum white, pale yellow at base, obcordate, 4–6 × 4–6 cm, apex 2-cleft. Filament ca. 3 cm; anther ca. 1.5 cm. Ovary sericeous. 2 *n* = 34 (Shu 2000).

Figure 1. *H. gardnerianum* at Mount Glorious, near Brisbane.

Figure 2. Mature seeds (red) being released from inside their orange capsules (photo: Brian Phillips).

Longevity

Colonies of kahili ginger have been observed to live for 70 years with no signs of dying out (Craw 1990).

Phenology

In New Zealand, *H. gardnerianum* flowering occurs from February to April (Auckland Regional Council 2002). However, *H. gardnerianum* flowering in Queensland has been observed all year round. In Hawaii, (northern hemisphere) bud initiation begins from May peaking in June–July, flowering peaks in July–August, immature fruits in August–October, and ripe fruit and seed is present from October–December (Medeiros 2004).

Reproduction, seed longevity and dispersal

Most dispersal of *H. gardnerianum* is via seeds, which are spread mainly by birds. Once established, a plant will spread radially by way of rhizomes, with new stems produced annually. New plants develop from broken sections of rhizome and, as such, can be spread by people dumping unwanted plants.

Seed production varies from 20–600 seeds per seed head, depending on light conditions (Byrne 1992). Rhodes (1986) reported seed numbers up to 900 seeds per seed head. Seed production tends to decrease as light levels decline under the forest canopy (Auckland Regional Council 2002). In dense infestations in Hawaii, seed production can be in the order of 2000 seeds/m^2 (Medeiros 2004).

In Hawaii, the main avian dispersers of *H. gardnerianum* seeds are two introduced passerines: Japanese white-eye (*Zosterops japonicus*) and the red-billed leiothrix (*Leiothrix lutea*) (Medeiros 2004). The red-billed leiothrix was also noted by Tassin and Riviere (2001) as an efficient candidate for the dispersal of *H. gardnerianum* on Reunion Island. Tassin and Riviere (2001) found that passage of seeds through the digestive tract of captive red-billed leiothrix significantly ($p<0.01$) increased germination, compared with fresh seeds that had not been eaten. However, Medeiros (2004) reported that there was no significant difference between germination rate for seeds that had passed through wild caught birds (77–85%) compared with uneaten fresh seeds (87%).

Field studies in the Reunion Islands suggest that the seeds of *H. gardnerianum* are short-lived with only 1–2% germination one year after seeds were sown in forest soil (Lavergne pers. comm.). Medeiros (2004) found that the highest establishment rate for *H. gardnerianum* seeds planted into natural situations was in an epiphytic site on moss covered tree branches (Table 1). Germination of *H. gardneriaum* seeds and successful growth in epiphytic sites has been observed in south-east Queensland (Figure 3).

Table 1. Establishment of *H. gardnerianum* after one year from Medeiros 2004.

Treatment description	No. plots with establishment	No. plants established from 250 seeds	Establishment rate	Plant height (mm)
Bare soil	4/10	12	4.8%	19.7 ± 6.2
Fernland	3/10	11	4.4%	27.0 ± 12.8
Grassland	3/10	3	1.2%	18.0 ± 3.6
Moss-covered tree branch	8/10	34	13.6%	10.9 ± 3.0

Figure 3. *H. gardnerianum* growing as an epiphyte in a hoop pine tree at Mount Glorious, Queensland (photo: Brian Phillips).

The ecology of *H. coronarium* has not been studied in any detail. Like *H. gardnerianum*, *H. coronarium* appears to be shade-tolerant, as indicated by its growth in partial shade at Kamakou Preserve. However, it can also grow in exposed (full sun) sites. Seeds are produced at lower elevations in Hawaii, but seeds have lower dispersal potential compared to *H. gardnerianum* because they are not displayed to avian vectors (Smith pers. comm. 1985).

Seeds are not produced on Hawaii Island at 1200 m elevation (Cuddihy pers. comm., Hawaii Volcanoes National Park, 1991). *H. coronarium* does not produce seeds at Kalopa State Park at 600 m (Tomich pers. comm., State of Hawaii, 1991). Exact elevation limits to seed production are not known. The pattern of distribution of *H. coronarium* at Kamakou Preserve has been attributed to dispersal patterns of rhizome fragments by water or road maintenance machinery.

H. flavescens does not set seeds in New Zealand (Williams et al. 2000) and probably spreads only from broken rhizomes.

History of introduction

This study was unable to determine when *H. gardnerianum*, *H. coronarium* or *H. flavescens* were first introduced into Australia. However, *H. coronarium* was cultivated in English glasshouses as early as the late 1700s and was noted as 'very rare' in *Curtis's Botanical Magazine* in 1803. *H. gardnerianum* was sent to England from India in 1819 by Dr Nathaniel Wallich of the Calcutta garden. The original specimen flowered and seeded in the Botanic Garden in Liverpool in October 1820. A specimen of *H. flavescens* was sent by Dr Carey from Serampore, (West Bengal near Calcutta) in 1821.

These and other *Hedychium* species were subsequently extensively cultivated in England and Europe, where their exotic forms and perfume made them prized subjects in 'tropical' hot-houses. From England, cultivation followed the paths of Empire and the various species were transported back to the warmer climates of the world (Orchard 1978).

The first recorded collection of *H. gardnerianum* in Australia was in 1968 at Ingleburn, near Sydney (J. Morton, pers. comm.).

In New Zealand, the first naturalised collection of *H. gardnerianum* was at Auckland in 1949 (Williams et al. 2003). In Hawaii, *H. gardnerianum* was wild collected in 1954 (Wester 1992), *H. coronarium* 1888 and *H. flavescens* in 1913.

Origin and worldwide distribution

H. gardnerianum is native to India and Nepal where it grows on the lower slopes of the Himalayas (to 1250 m) (Wood et al. 2000). It was originally collected in the Kathmandu Valley and subsequently in the Sikkim Himalaya and the Khasia Mountains at elevations of 120–2500 m (Weyerstahl et al. 1998). This study was unable to find detailed information on this species' natural habitat.

H. coronarium occurs in Guangdong, Guangxi, Hunan, Sichuan, Taiwan, Yunnan provinces in China; Bhutan, India, Indonesia, Malaysia, Myanmar, Nepal, Sikkim, Sri Lanka, Thailand and Vietnam (*Flora of China* 2000; Press et al. 2000).

H. flavescens occurs in forests from 500 to 800 m in Sichuan Province, China; India; and Nepal (*Flora of China* 2000; Press et al. 2000).

H. gardnerianum is distantly related to culinary ginger and has a faint smell and taste of ginger. There is some evidence that it was used as a ginger substitute during wartime rationing (NRC undated). There is also evidence that *H. coronarium* has been used for medicinal purposes—as a remedy for tonsillitis, swellings and as an anti-rheumatic—and appears to have been traded worldwide for these uses for hundreds of years. Moreover, it was introduced into Brazil by the Portuguese some 300 years ago and today is widespread in the neo-tropical region (Joly & Brandle 1995).

Distribution in Australia

H. gardnerianum occurs in Queensland, New South Wales, Victoria and Tasmania (Australian Virtual Herbarium data 2006) (Figure 4). *H. coronarium* occurs in south-east Queensland (Stanley & Ross 1989) and Far North Queensland (Hnatiuk 1990).

In Queensland, *H. gardnerianum* has been recorded at Mount Nebo, Mount Glorious, Buderim, Springbrook, Maleny and Mount Tamborine (all sites within south-east Queensland). *H. coronarium* has been collected from near Babinda and Millaa Millaa in North Queensland.

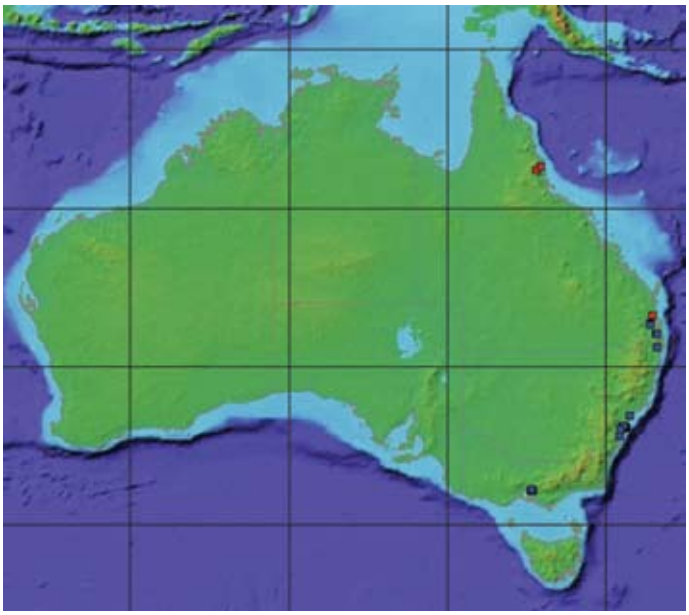

Figure 4. Herbarium records for *H. gardnerianum* (blue dots) and *H. coronarium* (red dots) (Australian Virtual Herbarium, 2006).

Preferred habitat and climate

H. gardnerianum prefers mesic (wet) habitats and fertile soils between sea level and 1700 m (Smith 1985). Habitat types recorded to have been invaded include rainforests (including beneath closed canopies), montane forests (e.g. in Hawaii and Jamaica), agricultural areas, coastland, disturbed areas, natural forests, planted forests, range/grasslands, riparian corridors, scrub/shrublands, urban areas and wetlands (PIER 2004).

In New Zealand, field studies show that *H. gardnerianum* grows most prolifically in open, light-filled habitats on forest margins and in clearings, as well as in particularly damp habitats (Byrne 1992). While it can certainly persist in semi and full shade beneath the forest canopy (Byrne 1992), colonies have been observed to die out following closure of the forest canopy above them (Esler 1988), presumably as light levels became too low. *H. gardnerianum* appears to rank as one of the more shade-tolerant invasive plant species in Queensland.

Byrne (1992) suggested that forest disturbance, combined with mass planting of kahili ginger in gardens, has facilitated invasion by kahili ginger in parts of New Zealand. A similar scenario appears to hold true in south-east Queensland. For example, infestations of kahili ginger around the township of Mount Glorious are invading forest that has a long history of human disturbance—from logging in the early to mid-20th Century, to fragmentation caused by the construction of tracks, roads, farms and powerline easements and the juxtaposition of human settlements. When large numbers of kahili ginger seeds are introduced into this disturbed system, via abundant garden specimens, rapid and conspicuous invasion is the outcome. Moreover, studies in New Zealand forests found that abundance of kahili ginger declines with distance from a forest edge, with highest abundance observed within the first 20 m of a forest margin and only the occasional plant observed at distances of more than 100 m into the forest—the so-called distance-decay pattern (Byrne 1992).

However, dense infestations have developed beneath closed rainforest canopies in Hawaii, suggesting that the distance-decay pattern of invasion may simply be an initial feature of the invasion process, with more extensive invasion occurring over a much longer timeframe. It may be relevant to note that kahili ginger has been present in Hawaii since the early 1900s and the population may have had more time to develop, compared with elsewhere in the world where populations are still in an earlier stage of expansion. Invasion by kahili ginger in some parts of Hawaii seemed to accelerate following removal of feral pigs, as part of management within some national parks (pigs presumably fed on the plant's rhizomes). It is not known whether feral pigs are currently helping to suppress kahili ginger in Queensland.

H. coronarium (white ginger) is native to eastern India (Dahlgren et al. 1985) and prefers humus-rich soils, shaded or semi-shaded areas subject to waterlogging, but never totally submerged (Joly & Brandle 1995).

Impact in other states

H. gardnerianum is naturalised in New South Wales and adventive in Victoria.

History as a weed overseas

H. gardnerianum is a major weed in the Azores Islands of the mid-north Atlantic Ocean, Hawaii, New Zealand and South Africa. It is also an emerging weed in Jamaica (Grubb and Tanner 1976), Madeira (Cronk and Fuller 1995), Cook Islands (Pacific), Micronesia (Pacific), La Reunion islands (Indian Ocean) and French Polynesia (Pacific) (PIER 2004).

In the Azores, *H. gardnerianum* poses a significant threat to native laurel-juniper forests and forms extensive, pure stands over entire hillsides. In addition to obvious environmental impacts, *H. gardnerianum* has substantial impacts on forestry in the Azores, where it has caused the death of entire forestry plots of pine and *Acacia melanoxylon* trees.

In Hawaii, *H. gardnerianum* has formed dense stands in mesic sites along streams and under closed rainforest canopies on several islands, where it is suppressing recruitment of native trees and displacing native understorey plants (Cuddihy & Stone 1990; Carroll 2004). *H. flavescens* and *H. coronarium* are also weedy, although these are usually confined to forest edges instead of invading the understorey (Anderson & Gardner 1999).

H. gardnerianum and its closely related congener, *H. flavescens* are both serious weeds in New Zealand where they have invaded large areas of indigenous forest in the northern part of the North Island (Williams & Timmins 1990; Byrne 1992; Porteous 1993).

H. gardnerianum was introduced into New Zealand in the 1890s and has become a major weed in some areas, such as the Waitakere Ranges, where it forms a dominant component of the forest understorey. Field studies have recorded up to 90% reduction of native seedling recruitment among dense colonies of adult ginger plants (Byrne 1992; Williams et al. 2003). At some sites, *H. gardnerianum* forms pure stands, replacing the native understorey and changing the character and structure of invaded forest communities (Byrne 1992). In addition to mesic forest habitats, *H. gardnerianum* has also invaded coastal dune communities, plantation forests and open cliffsides. In some regions of New Zealand, wild gingers are declared weeds and have been banned from sale.

In South Africa, *H. gardnerianum*, together with *H. coccineum*, *H. coronarium* and *H. flavescens*, are declared pests, due to their propensity to invade forests, plantations, riverbanks and other moist, shaded sites (Henderson 2001).

H. coronarium is a common weed in Peru (Holm et al. 1991).

H. flavescens (yellow ginger) is a significant pest in New Zealand and Hawaii. Smith (1985) ranks *H. flavescens* as one of the 86 most disruptive alien plants in Hawaii because of its capacity to form extensive single species stands. Morphologically, it is similar to *H. gardnerianum*, the main difference being its white flowers and the absence of seeds.

Meyer (2000) has reviewed the weed status of the *Hedychium* spp. in the Pacific Island nations as dominant (D), moderate (M) or potential (P): *H. coronarium*—Cook Islands (D); Federated States of Micronesia (M); Fiji (M); French Polynesia (P); Hawaii (D); Palau (P) *H. flavescens*—Cook Is (P); Fiji (M); French Polynesia (P); Hawaii (M); Samoa and American Samoa (P); *H. gardnerianum*—Hawaii (D).

Pest potential in Queensland

H. gardnerianum has a history as a major weed in New Zealand, Hawaii and the Azores, where it forms extensive pure stands. Hence, it is predicted to become a significant pest in areas of Queensland where climate and habitats are comparable to invaded areas overseas.

This study was unable to find accurate information on this species' natural distribution and preferred climate. However, the area generally described as the 'foothills of the Himalayas' is known to include humid, subtropical areas at low elevations and a cooler, temperate climate as the elevation increases. In the Himalayan region, climate varies with altitude. At about 2000 meters, the average summer temperature is near 18 °C; at 4500 m, it is rarely above 0 ˚C. In the valleys, summer temperatures reach between 32 °C and 38 °C. The eastern Himalayas receive as much as 1000–2000 mm more precipitation than do the western Himalayas, and floods are common.

Without accurate and detailed information on the location and altitudes where this species occurs naturally, it is difficult to predict its potential range in Queensland. However, it naturalised range may offer some clues on preferred climate.

Latitudinally, the native range of *H. gardnerianum* (on the lower slopes of the Himalayas) lies at approximately 26°N, which is comparable to Brisbane (26°S). However, unlike Brisbane, the lower slopes of the Himalayas include areas with a cool climate and this may be reflected by the observation that *H. gardnerianum* is only invasive in upland areas on the mountains around Brisbane.

The species' naturalised range offers clues about its preferred climate range, upon which predictions of potential range in Queensland can be based. Interestingly, Hawaii lies at approximately 19–22°, a tropical latitude that corresponds roughly to the region between Townsville and Mackay. In Hawaii, *H. gardnerianum* is a major pest from sea level up to an altitude of 1700 m (Smith 1985), with some dense infestations around 1500 m above sea level. For example, it thrives under a canopy of wet montane forest at the summit of the Kilauea Volcano (Hawaii Volcanoes National Park) (Carroll 2004).

This evidence suggests that it could thrive in cool, upland rainforests of North Queensland, probably only above 800 m (Mount Bellen-de Ker has an elevation of 1700 m above sea level). It may persist at lower elevations, but will probably struggle to survive due to high temperatures and seasonally dry conditions. The Azores lie at 38° (roughly the same as Melbourne) and the North Island of New Zealand lies between 35–41°—two places where *H. gardnerianum* has been particularly successful. These latitudes correspond roughly to the region between Tasmania and Canberra. Hence, it is predicted that *H. gardnerianum* will only thrive north of 35° at higher elevations, where temperatures are substantially lower than nearby lowland areas.

Climatically, *H. gardnerianum* appears best suited to the warm temperate zone, but can persist at high elevation in subtropical and even tropical latitudes. Edaphically, *H. gardnerianum* prefers fertile soils rich in organic matter. Habitats at risk within these climatic zones include mesic habitats, including:

- upland rainforests and wet sclerophyll forests within south-east Queensland (e.g. Lamington National Park, Springbrook, Mount Tamborine, Mount Glorious, Main Range National Park, Maleny) (elevation above 250 m)
- montane rainforests in North Queensland (elevation 800–1700 m)
- upland hoop pine plantations in south-east Queensland (e.g. Conondale ranges)
- disturbed sites with ample moisture in upland areas, including roadsides and abandoned farmland
- riparian habitats within upland areas.

It is important to note that *H. gardnerianum* prefers wet (mesic) conditions and that the most serious infestations around the world all appear to be located in moist habitats. Hence, it is predicted that habitats most at risk are areas under rainforest canopies, stream banks and moist forest edges. Experience from New Zealand suggests that *H. gardnerianum* can also invade littoral rainforest and even coastal dune communities. Since *H. gardnerianum* has invaded pine plantations in the Azores, it may have the potential to invade upland hoop pine plantations in south-east Queensland, such as those around the Conondale Ranges. *H. gardnerianum* has been observed growing within the margins of dry sclerophyll forest near Mount Glorious, suggesting it can persist in drier plant communities, presumably wherever there is sufficient soil moisture.

H. gardnerianum can germinate and grow in full shade, an attribute that is of particular concern as it allows the species to invade largely undisturbed rainforest and wet sclerophyll forest habitats. Few other weeds can persist beneath closed canopies. The thick rhizomes and heavy foliage cover prevent recruitment of native plant seedlings and could alter the structure and composition of rainforest and wet eucalypt forest habitats, in some cases totally destroying the understorey.

H. gardnerianum is not expected to become a significant weed of pastures since it is highly palatable and non-poisonous to stock (NRC undated).

A prediction of the potential range of *H. gardnerianum*, based on climatic suitability, has been generated using the CLIMEX computer modelling program (Figure 5). Batianoff and Butler (2002) ranked *H. coronarium* at 124 and *H. gardnerianum* at 171 in their assessment of 200 current environmental weeds in south-east Queensland.

H. coronarium is reported to be an alternative host to banana bunchy-top virus (BBTV) in Taiwan (Su et al. 1992). In Queensland, the BBTV vector banana black aphid *Pentalonia nigronervosa* is reported from *H. coronarium* (Geering & Thomas 1997). However, attempts by DPI&F to inoculate *H. coronarium* with an Australian isolate of BBTV (BBTV-482) failed (Geering & Thomas 1997), as did an attempt in India with an Indian isolate (Manickam et al. 2002). Geering and Thomas (1997) suggested that the difference in susceptibility of *H. coronarium* to BBTV could be explained by strains with different biological properties. Australian and Indian strains belong to South Pacific sequence group while those in Taiwan to the Asian Group (Karan et al. 1994). An alternative hypothesis put forward by Geering and Thomas was that there was variation in the populations of *H. coronarium* in the presence of resistance genes to the virus. Whatever the susceptibility *H. coronarium* in Queensland to BBTV, it can still play a part in the epidemiology of BBTV by acting as a reservoir of the virus vector *P. nigronervosa*. The extent of utilisation of *H. gardnerianum* and *H. flavescens* by *P. nigronervosa* is unknown.

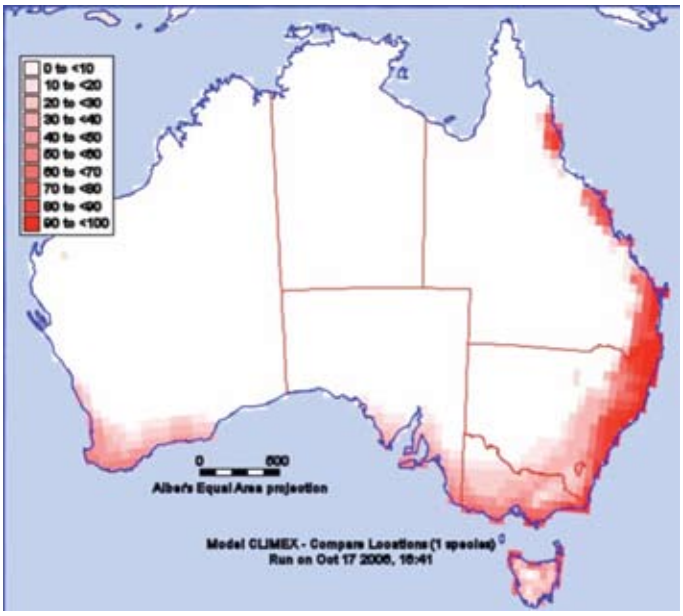

Figure 5. Potential range of *Hedychium gardnerianum* modelled using Climex from data on its distribution in the Himalayan region (dark red indicates highest suitability).

Benefits

H. gardnerianum, *H. flavescens* and *H. coronarium* are popular garden plants and are widely available in nurseries, garden centres, markets and are often swapped among gardeners (Blood 2001).

Related species of concern

Other invasive congeners include *H. coccineum* Buch.-Ham. (red ginger lily) (Csurhes & Edwards 1998; Randall 2002). *H. coccineum* is a weed in South Africa and Jamaica (Henderson 2001; Blood 2001; PIER 2004).

Control

Physical removal, such as digging, is an effective form of control provided the whole plant is removed, complete with rhizomes (Auckland Regional Council 2002). However, the large, thick, deeply rooted nature of the rhizomes can make manual removal difficult and costly. Any fragments of rhizomes left lying on the ground can regrow.

In New Zealand, successful control has been achieved using metsulfuron methyl, applied as a foliar spray (Auckland Regional Council 2002). Tall plants can be chopped down and the regrowth sprayed when it is 50–60 cm tall. Death of rhizomes can take 12–15 months (Auckland Regional Council 2002).

In Hawaii, *H. gardnerianum* can dominate early successional sites in some rainforest types after fire (Tunison et al. 2001). Given the sensitivity of areas potentially invaded by *H. gardnerianum* fire would not be a suitable tool for the control of *H. gardnerianum*.

Biocontrol research has been investigated in Hawaii at the Pacific Islands Ecosystems Research Centre (Anderson and Gardner 1999; USGS 2005). A highly host-specific, wilt-causing bacterium (*Ralstonia solanacearum)* was found to attack *H. gardnerianum*. Spray suspension of the bacterium reduced the number of fruiting bodies, stunted growth at apical meristems, wilted leaves and induced degradation of rhizomes. Further research will attempt to demonstrate effectiveness of large scale application in Hawaii Volcanoes National Park. This bacterium does not infect *H. coronarium* or *H. flavescens* (Anderson & Gardner 1999).

References

Anderson, RC and Gardner, DE (1999). 'An Evaluation of the Wilt-Causing Bacterium *Ralstonia solanacearum* as a Potential Biological Control Agent for the Alien Kahili Ginger (*Hedychium gardnerianum*) in Hawaiian Forests', *Biological Control,* 15: 89–96.

Auckland Regional Council (2002). 'Wild ginger (*Hedychium gardnerianum* and *H. flavescens*)', *Pestfact No. 28*.

Batinoff, GN and Butler, DW (2002). 'Assessment of invasive naturalised plants in south-east Queensland', *Plant Protection Quarterly* 17(1).

Blood, K (2001). *Environmental Weeds: a field guide for south-east Australia*, p. 146–7, Weeds CRC, University of Adelaide.

Bomford M (2003). *Risk Assessment for the Import and Keeping of Exotic Vertebrates in Australia*, Bureau of Rural Sciences, Canberra.

Byrne, J (1992). 'Wild ginger: aggressive invader of New Zealand's native forests', *Horticulture in New Zealand*, Vol. 3, No. 2.

Carroll, NW (2002). 'Invasive kahili ginger and forest bird density in Volcanoes National Park, Hawai'i, Elepaio', *Journal of the Hawaii Audubon Society,* 64(3): 17–23.

Craw, J (1990). 'Ginger problem at crisis point', *Conservation Summer*, p. 4, Department of Conservation (New Zealand).

Cronk, CB and Fuller, JL (1995). *Plant invaders: the threat to natural ecosystems*, Chapman Hall, London, UK.

Csurhes, SM and Edwards, R (1998). *Potential environmental weeds in Australia: candidate species for preventative control*, Environment Australia, Canberra.

Cuddihy, LW and Stone, CP (1990). *Alteration of native Hawaiian vegetation*, Co-operative National Park Resources Studies Unit, University of Hawaii, Manoa.

Dahlgren, RMT, Clifford, HT and Yeo, PF (1985). *The families of the monocotyledons—structure, evolution and taxonomy*, pp. 360–363, Springer-Verlag, Berlin.

Esler, AE (1988). Naturalisation of plants in urban Aukland, DSIR Publishing, Wellington, New Zealand.

Flora of China Editorial Committee, eds. (2000). 'Flagellariaceae through Marantaceae', *Flora of China,* Vol. 24, Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis.

Geering, ADW. and Thomas, JE (1997). Search for alternative hosts of banana bunchy top virus in Australia, *Australasian Plant Pathology,* 26: 250–254.

Grubb, PJ and Tanner, EVJ (1976). The montane forests and soils of Jamaica: a reassessment, *Journal of Arnold Arboretum*, 57: 313–368.

Hawaiian Botanicals (2006). www.hawaiianbotanicals.com/gingers.html (accessed 14.03.2006).

Henderson, L (2001). 'Alien weeds and invasive plants: a complete guide to declared weeds and invaders in South Africa', *Plant Protection Research Institute Handbook No. 12*, Agricultural Research Council, LNR: South Africa.

Hnatiuk, RJ (1990). 'Census of Australian Vascular Plants', *Australian Flora and Fauna Series No. 11*, Bureau of Flora and Fauna, Australian Government Publishing Service, Canberra.

Holm, LG, Pancho, JV, Herberger, JP and Plucknett, DL (1991). *A Geographical Atlas of World Weeds*, Kreiger Publishing, Florida.

Joly, CA and Brandle, R (1995). Fermentation and adenylate metabolism of *Hedychium coronarium* JG Koenig (Zingiberaceae) and *Acorus calamus* L. (Araceae) under hypoxia and anoxia, *Functional Ecology,* 9: 505–510.

Karan, M, Harding, RM and Dale, JL (1994). 'Evidence for two groups of banana bunchy top virus isolates', *Journal of General Virology*, 75: 3541–3546.

Lavergne, C (pers. comm.) (2005). Invasive plant and conservation ecologist, Reunion Island.

Manickam, K, Doraiswamy, S, Ganapathy, T and Rabindran R (2002). 'Early detection of banana bunchy top virus in India using polymerase chain reaction', *Acta phytopathologica et entomologica hungarica*, 37(1–3): 9–16.

Medeiros, AC (2004). Phenology, reproductive potential, seed dispersal, and seedling establishment of three invasive plant species in a Hawaiian rain forest, PhD thesis, University of Hawaii, Manoa, Hawaii.

Meyer, J-Y (2000) 'Preliminary review of the invasive plants in the Pacific islands (SPREP Member Countries)', *Invasive species in the Pacific: A technical review and draft regional strategy*, Greg Sherley, technical ed., 190p, South Pacific Regional Environment Programme, Samoa.

Natural Resource Management Standing Committee (2004). *Guidelines for the import, movement and keeping of exotic vertebrates in Australia,* www.feral.org.au/ref_docs_images/VPCGuidelinesApril05.pdf (accessed 18.10.2006).

NRC (undated). Wild ginger, *Pest Fact No. 4*, Northland Regional Council, New Zealand.

Orchard, AE (1977). *Hedychium* in New Zealand—a further name change, *New Zealand Journal of Botany.* 16: 287–89.

Pheloung, PC (1996). *CLIMATE: A system to predict the distribution of an organism based on climate preferences*, Agriculture Western Australia: Perth.

Pheloung, PC (2001). Weed risk assessment for plant introductions to Australia, *Weed Risk Assessment*, pp. 83–92, RH Groves, FD Panetta and JG Virtue (eds), CSIRO Publishing, Melbourne.

PIER (2004). Pacific island ecosystems at risk database, www.hear.org/pier/species/hedychium_gardnerianum.htm (accessed 18.10.2006).

Porcher, MH et al. (1995–2020). Sorting Hedychium Names, Multilingual Multiscript Plant Name Database—A Work in Progress, Institute of Land and Food Resources, University of Melbourne, Australia, www.plantnames.unimelb.edu.au/Sorting/Hedychium.html (accessed 30.10.2006).

Porteous, T (1993). *Native forest restoration*, Queen Elizabeth II National Trust, Wellington, New Zealand.

Press, JR, Shrestha, KK and Sutton, DA (2000), *Annotated Checklist of the Flowering Plants of Nepal*, Natural History Museum, London.

Randall, RP (2002). *A Global Compendium of Weeds*, RG and FJ Richardson, Melbourne.

Rhodes, D (1986). Wild ginger: Identification and control, *Protect—Official Journal of the Institute of Noxious Plants Officers Inc.*, 7(5): 18–22.

Shu, JH (2000). 18. HEDYCHIUM, *Flora of China,* 24: 370–377, http://flora.huh.harvard.edu/china/PDF/PDF24/hedychium.pdf (accessed 23.10.2006).

Smith, CW (1985). *Impact of alien plants on Hawai'i's terrestrial ecosystems: preservation and management*, Cooperative National Park Resources Studies Unit, University of Hawaii, Manoa, pp. 191–192.

Stanley, TD and Ross, EM (1989). *Flora of south-eastern Queensland*, Vol. 3, Queensland Department of Primary Industries, p. 356.

Su, H-J, Wu, R-Y and Tsao, L-Y (1993). 'Ecology of banana bunchy-top virus disease'. *Proceedings: International Symposium on Recent Developments in Banana Cultivation Technology,* pp. 308–312, RV Valmayor, SC Hwang, R Ploetz, SW Lee and VN Roa (eds), Los Baños, Philippines: International Network for the Improvement of Banana and Plantain/ASPNET.

Sutherst RW, Maywald GF, Yonow T, Stevens PM (1998). *CLIMEX. Predicting the effects of climate on plants and animals. User guide*, CSIRO Publishing: Melbourne.

Tassin, J and Rivieros, J-N (2001). 'Le rôle potentiel du Leiothrix jaune *Leiothrix lutea* dans la germination de plantes envahissantes à la Réunion (Océan Indien)', *Alauda*, 69(3): 34–41.

The Nature Conservancy (2005). The Global Invasive Species Initiative, *Hedychium gardnerianum*, http://tncweeds.ucdavis.edu/esadocs/hedygard.html updated January 2005 (accessed 16.10.2006).

Tunison, JT, D'Antonio, CM and Loh, RK (2001). 'Fire and invasive plants in Hawai'I, Volcanoes National Park', KEM. Galley and TP Wilson (eds.), *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species*, Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management, Miscellaneous Publication No.11, Tall Timbers Research Station, Tallahassee, Fl.

USGS (2005). United States Geological Survey, Biological Resources Discipline, Invasive Species Program, USGS Pacific Island Ecosystems Research Center (PIESC) http://biology.usgs.gov/invasive/Science%20Centers/PacificIslandPIERC.htm (accessed 18.10.2006).

Walton C (2005), 'Assessment of pests in Queensland', unpublished report to Department of Natural Resources and Mines, Brisbane.

Wester, L (1992). 'Origin and distribution of adventive alien flowering plants in Hawai'', pp. 99–154, CP Stone, CW Smith, and JT Tunison (eds), 1992, *Alien plant invasions in native ecosystems of Hawai'I*, Cooperative National Park Resources Studies Unit, University of Hawaii, Manoa.

Weyerstahl, P, Marschall, H Theeld, K and Subba, GC (1998). Constituents of the essential oil from the rhizomes of *Hedychium gardnerianum* Roscoe, *Flavour and Fragrance Journal,* 13: 377–388.

Williams, PA and Timmins, SM (1990). *Weeds in New Zealand protected natural areas: a review for the Department of Conservation*, Science and Research Series 14, Department of Conservation, Wellington, New Zealand.

Williams, PA, Nicol, E and Newfield, M (2000), 'Assessing the risk to indigenous New Zealand biota from new exotic plant taxa and genetic material', *Science for Conservation 143*, Department of Conservation, Wellington, New Zealand.

Williams, PA, Winks, C and Rijkse, W (2003). 'Forest processes in the presence of wild ginger (*Hedychium gardnerianum*)'. *New Zealand Journal of Ecology*, 27(1): 45–54.

Wood, TH Whitten, WM and Williams, NH (2000). 'Phylogengy of *Hedychium* and related genera (*Zingiberaceae*) based on ITS sequence data', *Edinburgh Journal of Botany*, 57(2): 261–270.

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