Review

The biology of Australian weeds 46. *Anredera cordifolia* (Ten.) Steenis

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Name

The genus *Anredera* Juss. (family Basellaceae), named after the Spanish word for vine or climber, *enredadera*, includes up to 12 species of perennial, twining or scandent, succulent or mucilaginous, often tuberous vines (Sperling 1987). Members of the genus are broadly distributed from southern USA (Florida and Texas) and Mexico, through Central and South America, from Colombia to Argentina, as well as Cuba, the Caribbean and the Galapagos. *Anredera cordifolia* (Ten.) Steenis (syn. *Boussingaultia cordifolia* Ten., *B. baselloides* (non H.B.K.) Hook, *B. gracilis* Miers, *B. gracilis* form *pseudobaselloides* Hauman, *B. gracilis* var. *pseudobaselloides* (Hauman) Bailey, *Anredera baselloides* Baill. and *B. cordata* Spreng.) is native to South America, Paraguay to southern Brazil and northern Argentina (Wagner *et al*. 1999). The many synonyms are indicative of earlier confusion regarding the taxonomy of the Basellaceae, as noted by Sperling (1987). The specific epithet, *cordifolia*, refers to the heart-shaped leaves of the species.

Common names include Madeira vine, potato vine, lamb's tail vine, mignonette vine, sweet mignonette, heart-leaf Madeira vine, jalap vine, white shroud, enredadera del mosquito, enredadera papa (hereafter described by its main common name Madeira vine).

Description

Madeira vine is a perennial, vigorous climbing vine, or in the absence of support, a scrambling shrub/ground cover. Stems are slender, twining and hairless to about 30 m long, initially green-pinkish-red and herbaceous, then becoming brown, exfoliating and woody with age and reaching 2–3 cm in diameter (Sperling 1987). Madeira vine produces fleshy tubers on both the roots (rhizomes to about 20 cm diameter) and at nodes on aerial stems. Aerial tubers are small irregular 'warty' light brown or green in colour and variable in size from 5 mm to about 25 cm in diameter, often bearing numerous axillary buds. Leaves are subsessile, subcordate, cordate or with a petiole to 1–12 cm (and less frequently up to 15 cm) long, alternate, broadly ovate, or sometimes lanceolate, heart-shaped ± fleshy to succulent depending on exposure; apex obtuse. The lamina is bright green in colour, darker green on upper surface, glossy, clammy to touch, 1–15 cm long by 0.8–11 cm wide. The inflorescence resembles a lamb's tail, and is a raceme 6–65 cm long slender and drooping; either simple or 2–4 branched. Flowers are about 3–5 mm in diameter, fragrant, greenish-white to cream-white, numerous and short-lived. The corolla is white, inflexed, the lobes ovate-oblong to elliptic, 1–3 mm long; apex blunt. Style and stamens are white. The style is shorter than stamens, 3-cleft branching halfway along the fused part to form three stigmatic arms, each with a club- or clavate-shaped stigma. Filaments are narrow-triangular, widely divergent, bending outwards near base pedicels 1.5–3 mm long. Each flower is subtended by a minute persistent bract 1.5–1.8 mm long; receptacle is cup-shaped by two persistent hyaline bracteoles, the upper bracteoles greenish white, flattened,

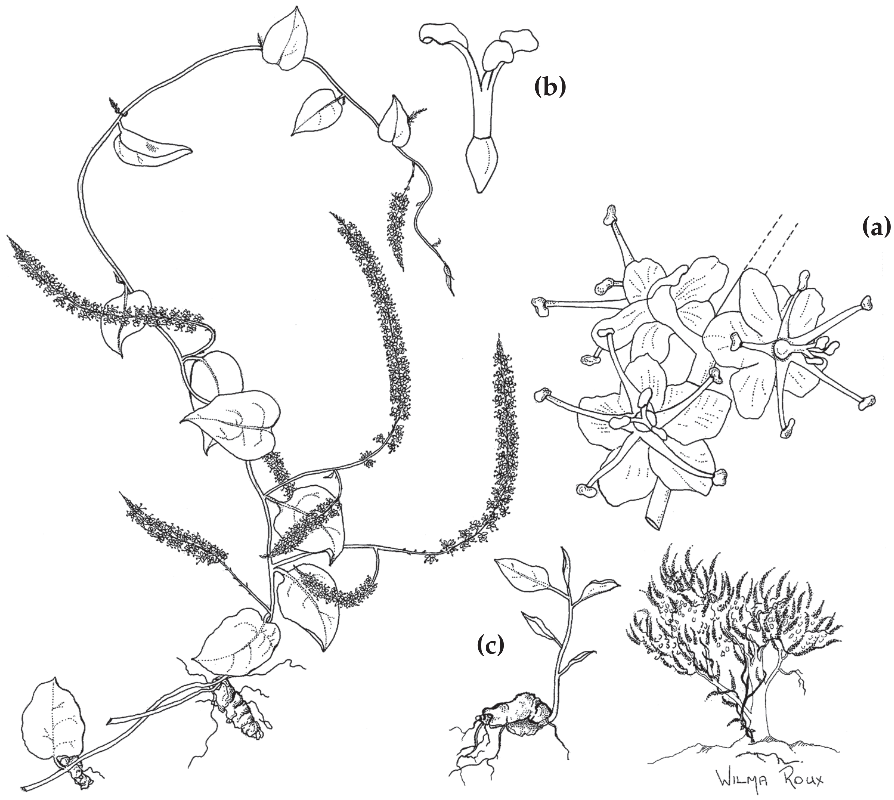

Figure 1. The form and identifying features of Madeira vine with insets showing flowers (a), three-cleft stigma (b), and shoots growing from an aerial tuber (c) (drawing by Wilma Roux, reprinted from Henderson (2001) with permission).

broadly elliptic to suborbicular, about 1–2 mm long and shorter than the perianth. Bracteoles are persistent after corolla is shed. The single seeded fruits are globose, slightly compressed to triangular, 0.9–1.1 mm long crowned by the enlarged fleshy tri-lobed style base, and loosely enclosed in the floral cup (van Steenis 1957, Sperling 1987, Webb *et al*. 1988, Harden 2000, Shu 2003). Seed production is rarely observed outside the native range (Sperling 1987, Swarbrick 1999).

History

In Australia, Madeira vine has naturalized following its introduction for ornamental purposes (see Floyd 1989). Madeira vine was a rare listing in early nursery catalogues from 1906 until 1920, with the first identified listing being in a 1906 Melbourne nursery catalogue produced by George Brunning and Sons in St. Kilda (Mulvaney 1991). However, the catalogues examined by Mulvaney (1991) were predominantly from temperate areas (Sydney, Melbourne, Canberra and Adelaide), and Madeira vine may have been sold more commonly in tropical and subtropical regions where it is more frequently cultivated. Irrespective, these records suggest a possible introduction to Australia over 100 years ago. Herbarium records from Queensland suggest that Madeira vine has been naturalized for at least 55 years (Batianoff and Butler 2002). The first report of Madeira vine being naturalized in New South Wales occurred a few years later in the 1960s at Wingham Brush in the north east of the State (Stockard 1983). By the late 1970s, the infestation of Madeira vine at Wingham Brush was such that mature trees had collapsed under the weight of the vines. By the 1980s it was deemed to be problematic over large areas of New South Wales and southern Queensland (see Floyd 1985), specifically in riparian vegetation, the edges of rainforest, tall open forest and damp sclerophyll forests (Csurhes and Edwards 1998). In south-eastern Queensland the species was ranked as fifth in terms of invasiveness and impact of 200 environmental weeds (Batianoff and Butler 2002). Madeira vine is now naturalized in all states except the Northern Territory (Swarbrick and Skarratt 1994, Blood 2002). While occurrences of the vine in Victoria, Tasmania (Blood 2002), South Australia and Western Australia (Swarbrick and Skarratt 1994) remain fairly isolated, it is expanding in all of these states. For example, in Tasmania, where there were no records of naturalization prior to 1970 (Rozefelds *et al*. 1999), Madeira vine is now reported as problematic in the north of the state (University of Tasmania 2003).

Distribution

Madeira vine is native to tropical and sub-tropical areas of South America, in particular Argentina, Bolivia, Brazil, Paraguay and Uruguay (Xifreda *et al.* 1999). Starr *et al*. (2003) reported the species as 'native from Paraguay to southern Brazil and northern Argentina' [p.1], located roughly between 20 to 30°S latitude. Sperling (1987), in a revision of the Basellaceae, notes the species is most abundant in its native range in southern South America from sea level to 3000 m. Lawson (1999) located records of Madeira vine on all continents except Antarctica, including South America (Bolivia, Ecuador, Paraguay, Peru), Mesoamerica (Costa Rica, Honduras, El Salvador), North America (the southern United States), Asia (China), Europe (France), Africa (Malawi, Senegal) and Australia. It has also been recorded on many islands throughout the Pacific region, including American Samoa, Cook Islands, Kermadec Islands, Hawaii, Lord Howe Island, Micronesia, New Zealand and Norfolk Island. Additional records show the species growing in Argentina, Brazil, Italy, Malaysia, Uruguay (Xifreda *et al.* 1999), South Africa (Henderson 2001), Sri Lanka (Ranamukhaarachchi *et al.* 1997, Marambe 2000) and Thailand (Royal Forest Department of Thailand 2005). Although regarded as a tropical and sub-tropical species, the worldwide distribution of the species suggests that its range extends into mild temperate climates.

Madeira vine is recorded in all Australian States and Territories, with the exception of the Northern Territory (Blood 2001) (Figure 2). Records of Madeira vine extend along the eastern seaboard of the continent between Cairns (17°S) and Hobart (43°S). The species has been recorded in Western Australia around Perth (Csurhes and Edwards 1998). A record of the species from Eulo in western Queensland (Queensland Herbarium HERBRECS record) reflects the current inland limit of the species in Australia (approximately 800 km from the coast), although it is reportedly spreading along watercourses in inland New South Wales (NSW) (Weeds Australia 2005). However, most Australian records are located in south-eastern Queensland and northern NSW, which is consistent with statements in the literature (Stanley and Ross 1983, Dunphy 1991, Swarbrick 1999) that highlight the invasiveness of the species in this region.

An assessment of the potential distribution of Madeira vine in Australia, based upon its distribution overseas using CLIMEX for Windows, Version 1.1a (Sutherst *et al*. 1999), suggests the species has a high potential for spread (Lawson 1999) (Figure 3). The model indicates that the species poses a significant threat to large areas of coastal and sub-coastal Australia, with some potential for growth in every State and Territory. Predictions show that the growth potential of the species is highest in the subtropical zone of south-eastern Queensland and north-eastern NSW. Crude estimates from this model suggest that 80 600 km^2 (1%) of Australia is highly suitable, 278 000 km^2 (4%) is suitable, and 1 387 700 km^2 (18%) is of marginal suitability for growth of Madeira vine.

Habitat

In its native range in South America, the species is located at 20 to 30°S latitude, with average temperatures ranging between 20 to 30°C in January, and 10 to 30°C in July. The region has an average annual rainfall of 500–2000 mm, comprising a diversity of vegetation types including forest, grassland, cropland, woodland and scrub (Hammond 1986, cited in Starr *et al.* 2003). In New South Wales, the species is considered most problematic in coastal areas with summer rainfall (Weeds Australia 2005).

Many sources note localized incursions mainly in areas of human settlement, on rainforest margins in coastal districts and riparian areas (e.g. Stanley and Ross 1983, Dunphy 1991, Harden 2000, Harden *et al.* 2004). Madeira vine is well recognized as a weed of urban gardens and waste areas (Esler 1988, Blood 2001). In Western Australia it has naturalized on the fringes of urban lakes (Swarbrick and Skarratt 1994) and has been found on Garden Island and along creeklines on the Swan Coastal Plain (Plant Protection Society of Western Australia 2003). The species is a major problem in lowland rainforest remnants and fertile floodplains (Floyd 1985, Anon. 2005) and in moist eucalypt forests (Swarbrick and Skarratt 1994, Blood 2001, Anon. 2005). On moist fertile soils, particularly in the above forest types, the species is an aggressive weed that can climb 40 m into tree canopies (Sydney Weeds Committee 2005). Aerial tubers of the species persist on the forest floor, often covered by leaf litter and silt from flooding (Floyd 1985, Harden *et al.* 2004). The species exhibits poor growth in low light conditions, but grows rapidly in high light environments (Floyd 1985). The effects of Madeira vine are most pronounced on the edges of vegetation remnants and in canopy gaps (Dunphy 1991), where it rapidly climbs into the canopy, and covers canopy trees (Floyd 1985, King 1988) (Figure 4).

In addition to the moist vegetation types detailed above, Carr *et al.* (1992) note that the species presents a threat to rock outcrop vegetation in Victoria, while Blood (2001) and West (2002) describe infestations of the species on cliff faces in Victoria and New Zealand, respectively. These are consistent with 'The Flora of Crete' (Chilton and Turland 2004) that lists the species as occurring on 'cliffs, rocks, rocky slopes'. Madeira vine is also recorded as a problem in dry coastal vegetation (Carr *et al.* 1992, Blood 2001). The occasional occurrence of the species on frontal dune systems (Blood

2001), mangroves (Weeds Australia 2005, G. Vivian-Smith personal observation) and coastal bluffs (West 2002) suggests some salt tolerance. The species is documented as having some frost tolerance (Stockard *et al*. 1985). Blood (2001) attributes Madeira vine's capacity to tolerate short periods of adverse conditions, such as drought, snow and frost, to the die-back of aboveground shoots during such periods.

Relationships with other species

Facilitation

The invasive vine, cat's claw creeper (*Macfadyena unguis-cati* (L.) A. Gentry) has been hypothesized as a facilitator species for invasion of rainforest remnants and fragments by Madeira vine (Floyd 1989). The increased light levels resulting from canopy collapse by cat's claw creeper are thought to create more favourable growth conditions for Madeira vine (Floyd 1989).

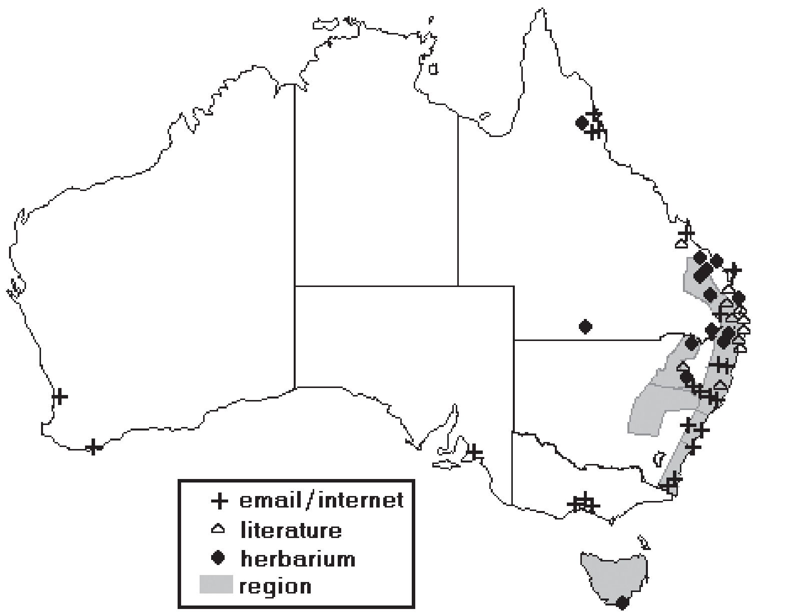

Figure 2. The recorded distribution of Madeira vine in Australia, detailing the sources of those records. Mainland regions are based on IBRA bioregions in Australia.

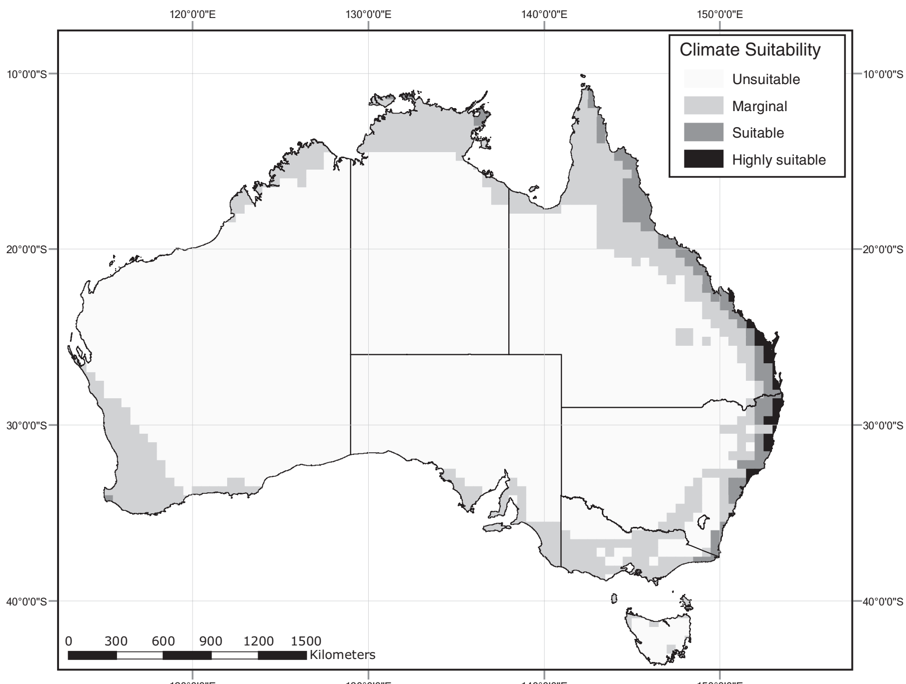

Figure 3. The predicted potential distribution of Madeira vine in Australia based on CLIMEX climate model with arbitrarily assigned growth classes (after Lawson 1999).

Cultivated relatives

Madeira vine can be confused with Ceylon or Malabar spinach (*Basella alba* L. or *B. rubra* L.), a related species within the Basellaceae that is cultivated in Australia. This species is grown as a green leaf vegetable in gardens in south-eastern Queensland and has fleshy leaves, rapid growth and a climbing habit very similar to Madeira vine (G. Vivian-Smith personal observation). It is also cultivated in South America, Africa and Asia, where the leaves are used as a vegetable and for medicinal purposes (van Steenis 1957). It produces fleshy, purple-reddish 'pseudoberries' with purple juice that is used as a food colouring (van Steenis 1957). Another related species, in the Basellaceae, that is traditionally cultivated as a native tuber crop in the Andes is ulluco, *Ullucus tuberosus* Loz. It is not known to be present in Australia, but has recently been reintroduced to New Zealand where it is being evaluated as a potential food crop (Busch *et al*. 2000).

Growth and development

Madeira vine shows prolific growth in high light environments, with seasonal growth of up to 6 m reported (van Steenis 1957). Other growth rates reported from anecdotal observations range from 1 m per month (Floyd 1989), to more than 1 m per week during warmer months (Stockard *et al*. 1985). Cummings (1999) measured stem growth, recording a mean stem elongation of 101.6 cm from potted tubers over eight weeks in a summer glasshouse experiment, suggesting that growth rates are likely to vary with factors such as growing conditions and plant resource reserves. Reports indicate that Madeira vine growth is suppressed under low light conditions, compared to other invasive vines, such as *M. unguis-cati* (Stockard 1983, Stockard *et al*. 1985, Floyd 1985, 1989).

In addition to vertical growth, Madeira vine also produces large resource reserves in the form of subterranean tubers and aerial tubers that initially form in the leaf axils. Subterranean tubers, found to depths of 1 m, are commonly reported to reach 20 cm in diameter (Muyt 2001). Aerial tubers frequently reach 10–20 cm in diameter within established infestations (G. Vivian-Smith personal observation), but can reach 30 cm in diameter (Floyd 1989). Tubers drop off the parent vine or are dislodged through disturbance, growing into new plantlets or 'tuberlings' under favourable conditions.

Germination is phanerocotylar (i.e. free of seed coat) and epigeal (Swarbrick 1999). Seedlings are rarely observed, but are described as having fleshy oval-ovate cotyledons, a succulent hypocotyl and distinct juvenile leaves 5–10 mm in length, germinating from soil depths of several millimetres (Swarbrick 1999) (Figure 5).

Reproduction

Floral biology and phenology

Flowers appear bisexual but are often functionally unisexual (Sperling 1987). No pollination studies of Madeira vine have been identified. However, flowers are scented and produced in a large display, with stamens bearing a nectary at their base (Sperling 1987), suggesting pollination by insects. The flowers of Madeira vine plants in Maui (Hawaii) were noted to attract potential pollinators, including various Hymenoptera (including bees, wasps, and ants) but did not set fruit (Starr *et al*. 2003). Inflorescences of several other members of the genus are reported to be attractive to flies in their native range (Sperling 1987). Flowers are present in summer, peaking in autumn (in Australia, December to May) (Muyt 2001).

Seed production and dispersal

Sperling (1987), in a revision of the Basellaceae, reported that seeds were rarely produced in cultivated plants, but were not infrequent in wild plants from southern South America, with fruit production common in Bolivia, Argentina, Uruguay, Paraguay and Brazil. Xifreda *et al*. (1999) noted that the occurrence of fruit with seed production was one of several characters, in addition to chromosome number, that separated two intraspecific taxa in *A. cordifolia*, namely *Anredera cordifolia* (Ten.) Steen. subsp. *cordifolia* and *A. cordifolia* subsp. *gracilis* (Miers) Xifreda & Argimón. One of these taxa, *A. cordifolia* subspecies *cordifolia* (n = 36 chromosomes), was found to be autotriploid, and is described as the more extensively cultivated herb with prolific tuber production. This subspecies produces abnormal pollen grains, and was concluded to have virtual sterility. Analysis of herbarium and live plant samples from wild populations of the other subspecies, *A. cordifolia* subsp. *gracilis* (n = 24 chromosomes) indicated the production of viable pollen, smaller flowers and fruit.

Madeira vine is reported not to produce seed in New Zealand (Esler 1988), China (Shu 2003) or Hawaii (Starr *et al*. 2003). In Australia, seed production is considered uncommon, with only one scientific record at Redwood Park, Toowoomba, Queensland (27°33″43.7′S, 151°59″50.3′E) (Swarbrick 1999). Additional anecdotal reports of seed production exist from Welk's Remnant and Dwyers Scrub Conservation Park, in the adjoining Lockyer Valley (T. Armstrong personal communication). Swarbrick (1999) suggested that seed production may only occur in the most favourable years and does not appear a major means of reproduction. In June 2005, viable seeds, confirmed via germination tests, were collected from three of four populations sampled on the Toowoomba Range, including the Redwood Park population (G. Vivian-Smith unpublished data). It was estimated that between 0.2–5.4% of the dried flowers present contained germinable seeds (G. Vivian-Smith unpublished data). Genetic or pollination tests have not been conducted to determine why these populations produce seed, while the majority of populations in Australia are reportedly sterile. As flower production is prolific, seed input to the environment could well be significant, when it occurs. Seeds germinated readily under moist, light conditions in Petri dishes placed in a growth cabinet with an alternating 12 h thermo/photoperiod (15/25°C) (G. Vivian-Smith unpublished data).

The seed is contained in a globose, indehiscent capsule (0.9–1.1 mm long) that retains the perianth (Sperling 1987, Xifreda *et al*. 1999), and is without an obvious means of dispersal, although Swarbrick (1999) speculates that movement of soil or water may result in dispersal. The retained perianth makes it difficult to differentiate seeds from dry, spent flowers on old inflorescences (potentially limiting observations of seed set), and may also aid in seed dispersal by enhancing buoyancy in wind or water (G. Vivian-Smith personal observation).

Vegetative reproduction

Madeira vine's major means of reproduction is through asexual tubers on roots and stems (Sperling 1987). In addition to tubers, vegetative reproduction can occur from stems and rhizomes (Brickell 1996). Axillary tubers are produced at nodes and can be highly variable in morphology, with some bearing many warty or finger-like protuberances, while others are more globose in shape. These tubers may be found at densities of over 1500 m^{-2} on the forest floor, under heavy infestations of the vine (Stockard 1983, Stockard *et al*. 1985, Floyd 1985). In other areas, tuber production is also heavy, with reports of 7.5 tonnes of tubers removed from two locations over a four year eradication attempt on Raoul Island, New Zealand (West 2002).

Figure 4. An infestation of Madeira vine, showing its growth habit.

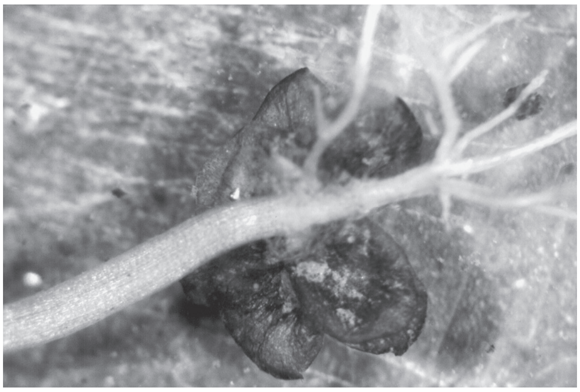

Figure 5. Photograph of a Madeira vine seedling emerging from attached remains of the persistent perianth. Seeds were collected at Welk's Remnant, south-eastern Queensland and germinated at the Alan Fletcher Research Station in 1998.

Dispersal

Madeira vine is primarily dispersed by anthropogenic means, gravity and water (Dunphy 1991). Intentional human-mediated spread of Madeira vine occurs via cultivation for ornamental purposes, with early transport of the vine from South America thought to be via Spanish and Portuguese traders (Sperling 1987). Unintentional escape into neighbouring natural areas and over longer distances has occurred via the dumping of garden waste containing tubers, rhizomes and other viable plant fragments (Starr *et al*. 2003). In large infestations, aerial tubers drop to the ground at maturity, following physical disturbance (G. Vivian-Smith personal observation), when the parent plants experience stress (Prior and Armstrong 2001), or following manual control (Stockard 1993, P. Downey personal observation). Measurements of tuber dispersal (monthly assessment of tuber deposition in raised traps placed under vine canopies) over 24 months at infestations (n >5) in south-eastern Queensland indicate continuous tuber deposition throughout the year (G. Vivian-Smith unpublished data).

Secondary dispersal of such tubers may occur following flooding events or other disturbances (Pallin 2000, Vivian-Smith and Panetta 2002). Localized dispersal via sea currents is also suspected (West 2002), but the salinity tolerance of tubers has not been tested. The potential for freshwater water dispersal has been investigated by testing buoyancy of tubers placed in floating cages in an experimental pond (Vivian-Smith and Panetta 2002). Madeira vine tubers showed poor floating ability, with most tubers sinking in less than a day. However, two of the 375 tubers tested remained floating and viable for the entire 30 days duration of the experiment. This suggests that occasional long distance dispersal of individual tubers by water is possible. A significant proportion (33%) of tubers survived 30 days in water, indicating that tuber viability after prolonged flooding could be significant. Despite low tuber buoyancy, dispersal of Madeira vine is likely during major flooding events, when rafts of dislodged vegetation containing vines and tubers are transported downstream. An additional disturbance resulting in secondary dispersal of Madeira vine tubers is the nest mound construction activities of brush turkeys (*Alectura lathami* Gray), potentially concentrating tubers in turkey nest mounds (Westermann 2000).

Lowe (2000) observed that vertebrate tuber herbivores could potentially act as dispersers via removal and partial consumption of tubers. Via a simulated tuber herbivory (cutting tubers in half) experiment in the glasshouse, he found that herbivory treatments did not significantly affect shoot emergence or growth rates.

Hybrids

No records of hybridization in Madeira vine were identified. The work of Xifreda *et al.* (1999) (see earlier) suggests that the virtual sterility of *A. cordifolia* subsp. *cordifolia* would provide very limited opportunity for hybridization in this subspecies.

Population dynamics

There are no published studies of population dynamics of Madeira vine. Records indicate that in most cases, Madeira vine does not possess a seed bank, but has what is referred to as a 'bud bank' or 'meristem bank' (Cousens and Mortimer 1995). The meristem bank of Madeira vine is contained below the ground, on the soil surface and within the canopy of the vine, and largely comprises aerial and subterranean tubers. In such species, the shoot growth from tubers can be superior to that of seedlings due to the higher resource reserves available to the shoot, but tubers are frequently more vulnerable to desiccation than seeds, leading to potentially higher mortality (Cousens and Mortimer 1995).

Information or data enabling the development of a model describing the population dynamics of Madeira vine are lacking. Ideally such data would describe the seasonal rates of tuber production for different plant- and tuber-size classes, the length of time before independent ramets begin tuber production, rates of vegetative expansion (e.g. ramet production and growth), tuber and shoot mortality rates, the effects of different environmental variables (e.g. light and moisture) on growth and resource allocation, and the role of density dependence on these parameters.

Persistence

Anecdotal reports indicate that aerial tubers can persist for long periods ranging from two (Landcare 1995), to five (Stockard 1993), to 15 years (Harden *et al.* 2004). Subterranean tubers are thought to persist for between 5–10 years, with reports of resprouting occurring for up to 10 years despite annual herbicide application (Muyt 2001). Tuber persistence under experimental conditions is limited (G. Vivian-Smith unpublished data). Of 1100 tubers tested (ranging in size from <0.5–5 g fresh weight), no viability was reported after two years from a range of treatments including burial (0, 1 and 5 cm) or suspension from an artificial canopy.

Establishment from tubers

Lowe (2000) tested establishment from tubers following a range of experimental disturbance treatments in several habitats (i.e. closed forest, open eucalypt forest and cleared grassland). He found that shoot emergence was greater for larger (>10 g) than for smaller (0.5–10 g) tubers, but did not vary with habitat types. Disturbance treatments only altered emergence significantly in the most severe treatment (i.e. soil replacement with commercial potting mix), while a treatment of surface vegetation and litter removal had no significant effect. Shoot growth (changes in shoot length and leaf number) from tubers was not significantly different between habitats or disturbance treatments. Greater tuber predation was observed in the two forest habitats, particularly for the disturbance treatment involving soil replacement (Lowe 2000).

Shoot emergence from tubers in field and glasshouse experiments indicated mean shoot emergence rates were greater under glasshouse (45–100%) than field (0–30%) conditions (Lowe 2000). Cummings (1999) also reported 100% tuber establishment rates under irrigated glasshouse conditions. Shade treatments (0, 50 and 90%) in the glasshouse were also found to significantly reduce shoot emergence and growth (i.e. length and leaf number) from the tubers (Lowe 2000).

Importance

Detrimental

In Australia, Madeira vine was ranked 41st out of the 71 invasive plants considered during a national assessment for the Weeds of National Significance (Thorp and Lynch 2000), highlighting its current and potential status as one of Australia worst environmental weeds. In other countries Madeira vine is also a problematic weed. For example, in Hawaii (USA) the species is a listed noxious weed (Starr *et al.* 2003), in parts of New Zealand it is a declared pest species, and in South Africa it is also a declared weed (Henderson 2001).

Madeira vine is a significant environmental weed in New South Wales, Queensland and Victoria, and a garden escape in South Australia and Western Australia. In New South Wales, the impact of exotic vines, such as Madeira vine, has been acknowledged with a preliminary determination for listing as a key threatening process under the NSW *Threatened Species Conservation Act 1995* (see NSW SC 2005a). In the Northern Territory, Madeira vine is listed by the Northern Territory *Parks and Wildlife Conservation Amendment Act 1993* as a Prohibited Entrant. In Queensland, Madeira vine has been declared a Class 3 pest plant under the *Land Protection (Pest and Stock Route Management) Act 2002*, making it illegal to introduce, supply or sell the species anywhere in the state. In south-eastern Queensland, Madeira vine was ranked 5th in terms of invasiveness and impact from a list of 1060 naturalized plant species (Batianoff and Butler 2002). The NSW North Coast Weeds Advisory Committee ranked Madeira vine as the 7th most invasive environmental weed in the region due to its impact and difficulty to control (NCWAC 2001). Madeira vine has also been listed as one of the 10 most serious invasive garden plants species currently available for sale by nurseries in New South Wales (Groves *et al.* 2005). Such prioritization has not yet resulted in listings under the NSW *Noxious Weeds Act 1993* in the worst affected areas. Current declarations (13 in total) are all within the Sydney catchment (Campbelltown, Hornsby, Hunters Hill, Ku-ring-gai, Lane Cove, Manly, Mosman, North Sydney, Parramatta, Pittwater, Ryde, Warringah, and Willoughby) and Lord Howe Island. At time of writing, the declaration category W4c of the *NSW Noxious Weeds Act 1993* requires that: 'The weed must not be sold, propagated or knowingly distributed and the weed must be prevented from spreading to an adjoining property'. Madeira vine is considered most problematic in south-eastern Queensland (Stanley and Ross 1983) and northern New South Wales (Dunphy 1991). It is considered the most destructive weed of northern New South Wales rainforest remnants (King 1988, Dunphy 1991). Invasion by Madeira vine is well documented for the alluvial rainforest remnants at Wingham Brush (Stockard *et al.* 1985, Harden *et al.* 2004) and Bellingen Island in the mid-north of New South Wales (Floyd 1989), and a dry rainforest remnant at Rotary Park in Lismore, northern New South Wales (King 1988), all sites being the subject of intensive restoration efforts.

Madeira vine infestations threaten the following endangered ecological communities listed under the NSW *Threatened Species Conservation Act 1995* – i) 'Swamp Sclerophyll Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions' (See Keith and Scott, in press), ii) 'Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions' (NSW SC 2004), and iii) 'River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions' (NSW SC 2005b, Coutts-Smith and Downey, in press). In addition, Madeira vine is also considered detrimental to riparian vegetation, tall open forest and damp sclerophyll forests (Floyd 1989).

In the worst affected areas, the species quickly covers the canopy, reducing trees to 'vine-shrouded pole-like structures' (Floyd 1989). Madeira vine is considered to be the heaviest of the problem vine species in subtropical Australia, due to its prolific tuber production and vegetative growth (Floyd 1989). This often leads to collapse of supporting vegetation (Stockard *et al.* 1985), further compromising the structure and functioning of the affected vegetation. Germination and regeneration of native species is inhibited by dense growth of Madeira vine (Harden *et al.* 2004, Anon. 2005).

Madeira vine is also known to threaten four species listed as endangered under the NSW *Threatened Species Conservation Act 1995*, being Illawarra socketwood (*Daphnandra* sp. C. Illawarra (R. Schodde 3475)) and ripple-leaf muttonwood (*Rapanea* sp. A Richmond River (J.H. Maiden & J.L. Boorman NSW 26751)), Nilsen Park she-oak (*Allocasuarina portuensis* L.A.S.Johnson), and Coxens double-eyed fig parrot (*Cyclopsitta diophthalma coxeni* Gould) (Coutts-Smith and Downey in press).

Toxicity Stanley and Ross (1983) note that Madeira vine can be poisonous to stock but it is rarely eaten. Everist (1974) also notes that field cases of poisoning attributed to Madeira vine are rare, comprising suspected poisoning of drinking water by Madeira vine followed by sudden death. In feeding trials, cattle fed 9.5 kg of freshly cut flowering foliage exhibited no ill effects, while sheep and pigs fed 1.8 kg over two days exhibited temporary diarrhoea before recovering (Hurst 1942). Tuber toxicity appears to be untested. Lowe (2000) noted tuber predation in field plots by red-necked wallabies (*Macropus rufogriseus* Desmarest), rodents, slugs and snails.

Beneficial

Madeira vine has been introduced to many areas of the world as an ornamental plant for its thick, glossy foliage and tassels of fragrant white flowers (Bailey 1975, Floyd 1989). Future Foods (2004) indicate that both tubers and leaves, although unappealing in taste and texture, can be eaten raw or cooked; the authors note that no reports on edibility or potential toxic effects were identified. We suggest that the investigation of potential toxicological effects of Madeira vine tuber consumption by humans may be warranted, given reports of toxic effects of consumption of Madeira vine on livestock reported in the literature (see above). Madeira vine was often planted near outdoor toilets because it was thought that eating the leaves could have a laxative effect (Anon. n.d.). The axillary bulbils, leaves and tubers are used medicinally (Shu 2003). In Taiwan, the species is used for its medicinal properties, with hypoglycaemic activity of extracts demonstrated in mice (Lin *et al.* 1988), and anti-inflammatory, liver-protective (Lin *et al.* 1994), and relaxant effects of extracts demonstrated in rats (Lin *et al.* 1997). The plant has also been used as a folk medicine analgesic and for the symptomatic treatment of diabetes mellitus in Taiwan (Lin *et al.* 1988). Ethnobotanical reports note use of Madeira vine for treatment of sexually transmitted diseases (Tshikalange *et al.* 2005). The close relative of Madeira vine, *A. versicaria* (Lam.) C.F.Gaertn., is also cultivated and used medicinally by wrapping the succulent plant around bruises, fractures and broken bones (Sperling 1987).

Weed management

In Australia, Madeira vine has been recognized as a potential environmental weed and as a candidate species for preventative control (Csurhes and Edwards 1998). Effective eradication or control of this plant takes considerable effort and patience over a long period of time (Blood 2002). The size and longevity of subterranean tubers, the number of aerial tubers produced and the lack of susceptibility of the tubers to herbicide present considerable management challenges (Muyt 2001).

Herbicides

The control of Madeira vine can be achieved through the use of selective or non-selective herbicides (Muyt 2001). Challenges reported include the production of viscous exudates from cut stems which inhibit herbicide uptake (Stockard 1993) and the difficulty in achieving upward translocation of herbicide and death of the aerial tubers (Muyt 2001).

Historically, bush regeneration methodology has been applied to the management of Madeira vine in Australia. Methods are varied, but frequently utilize the stem-scrape and paint, or stem-cut and paint methodology (Muyt 2001), or stem injection techniques (Stockard 1993). Typically, the scrape and paint technique involves carefully scraping a 20 cm length of stem to expose the cambium and immediate application of undiluted herbicide (e.g. Roundup® glyphosate 360 g L^{-1}). Cut and paint involves cutting the stem and immediately applying undiluted herbicide to the cut surfaces. Stem injection involves injecting vines with a pressurized syringe with 2–3 mL of Roundup to allow for translocation into the tubers. Basal bark applications of Vigilant® gel (picloram 43 g L^{-1}) to vines in Bellingen (New South Wales) were observed to result in successful control; however impact on aerial tubers was not determined (I. Turnbull personal observation).

Foliar applications are used where large numbers of vines render the application of the more labour-intensive, localized application methods impractical. Generally, vines are cut and allowed to reshoot prior to herbicide application. Regrowth from vines and sprouting tuberlings is then sprayed with 1:50 glyphosate:water (Stockard 1993). This method has been found to control 70–80% of stem tubers (BRAIN 1995). Hayley (1997) cited in Starr *et al.* (2003) recommends, after all tubers are removed, a foliar spray of Escort® (metsulfuron methyl 60% by weight), Roundup (glyphosate 360 g L^{-1}) and Pulse® (organosilicate penetrant/surfactant) on plants and tubers as soon as green sprouts have two or four leaves on each sprout. Timing of follow-up spraying is important because if left too long, new subterranean tubers will form, prolonging the control effort. Wildy (2004) suggests applying a foliar spray of Garlon 4® (triclopyr) mixed with water at 5 mL L^{-1}. Vine weed control trials held at Murphy's Creek in Queensland found that both fluroxypyr and metsulfuron methyl high volume foliar application killed Madeira vine, but regrowth from tubers occurred with both chemicals (Armstrong and Keegan 1996). Prior and Armstrong (2001) compared the efficacy of one, two and three foliar applications of various concentrations of glyphosate and fluroxypyr ester on Madeira vine. Fluroxypyr applied at 1 and 2 g L^{-1} of water and glyphosate applied at 3.6 and 7.2 g L^{-1} of water were effective in controlling treated stems. However, fluroxypyr at these rates was the only herbicide resulting in significantly less regrowth of new stems from subterranean tubers in the months between applications. These authors also reported that the removal of competing vegetation through the use of the non-selective herbicide glyphosate may favour regrowth from subterranean tubers, especially if applied when translocation of herbicides to the roots is low.

The Australian Pesticide and Veterinary Medicines Authority (APVMA) database reports only three products with Madeira vine included on their label; all contain fluroxypyr (220 g L^{-1}) as the active ingredient. Two Minor Use permits (7485 and 5206) allow for the use of glyphosate at 10 g L^{-1} and 1:50 respectively (APVMA 2005).

Mechanical

Mechanical removal is generally only considered practical in localized infestations where follow-up control, either mechanical or chemical, is readily available. Subterranean tubers can be dug out, but all tubers must be removed to prevent regrowth (Muyt 2001). Vine cutting can result in increased recruitment of plants from aerial tubers falling from the dying vine (Stockard 1993). It is therefore recommended that aerial tubers be removed from the vine where possible, prior to vine cutting (Muyt 2001), with a tarpaulin being placed below the vine to facilitate collection and disposal of falling tubers (BRAIN 1995, Sutherland Shire 2003). Stockard (1993) reports that aerial tubers and stems held in the canopy can be pulled down using aluminium extension poles with hooks attached; other workers recommend the use of pruning saws to cut tubers from the canopy (Muyt 2001). Disposal of collected tubers is an important factor in preventing reinfestation (West 2002). In a New Zealand eradication program on Raoul Island, more than 7.5 tonnes of tubers were collected during a four year period, with disposal involving bagging tubers in plastic for transport, placing them in a desiccator, and finally burning them (West 2002).

Biological control

An application has been made to declare Madeira vine a biological control target in Australia (Dhileepan and Palmer 2005), with the application currently under consideration by the Australian Weeds Committee (B. Wilson personal communication). Madeira vine is considered to be a good biological control target in Australia, with a high probability of finding an agent with the required host-specificity, as there are no native representatives of the family Basellaceae in Australia (Dhileepan and Palmer 2005). Exploratory surveys for natural enemies in Brazil and Argentina have collected several potential biocontrol agents for potential use in South Africa (Gandolfo *et al*. 2004, van der Westhuizen 2005, 2006). These surveys have resulted in the identification of damaging insects, including leaf-feeding chrysomelids and lepidopterans, as well as a fungal pathogen (van der Westhuizen 2005). One potential candidate, a leaf-feeder *Plectonycha correntina* Lac. (Chrysomelidae), is undergoing host-specificity testing in South Africa. Results indicate that this species has a narrow host range, with feeding and development occurring on some related species, including *Basella alba*, *Ullucus tuberosus* (both Basellaceae) and *Talinum paniculatum* (Jacq.) Gaertn. (Portulacaceae) (Gandolfo *et al*. 2004). The authors suggest that this agent has potential for biocontrol. A damaging leaf spot fungus, *Alternaria alternata* Fr.: Fr. Keissl., has also been reported on Madeira vine in Taiwan (Lai *et al.* 1996), but has not been considered for biocontrol.

Madeira vine has also been considered as a target for biological control in New Zealand (Syrett 2002). However, a ranking process for biological control of weed target species in New Zealand downgraded the importance of Madeira vine due to its lack of seed production (Syrett 2002).

Cultural control

The Bushland Friendly Nursery Scheme operating on the NSW North Coast promotes nurseries that do not sell environmental weeds, including Madeira vine (BFNS 2005).

Fire

Trials undertaken by Armstrong and Prior (1997) found that the average growth of aerial tubers was not significantly reduced following treatment with a Weed Dragon® propane burner. No published studies investigating the effects of prescribed autumn and spring fires on Madeira vine infestations were identified.

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