Review

The Biology of Australian Weeds
26. *Cryptostegia grandiflora* R. Br.

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Name

The genus *Cryptostegia* (Asclepiadaceae: Periplocoideae) is endemic to Madagascar, and contains only two species, *C. grandiflora* (Roxb. ex R. Br.) and *C. madagascariensis* (Bojer ex Decne.) (Marohasy and Forster 1991). *Cryptostegia* is derived from the Greek *crypto* (hidden) and *stegium* alluding to the stamens being concealed within the corolla tube, *grandiflora* referring to the large showy nature of the flowers. The genus was founded on a single species *Cryptostegia grandiflora* Roxb. R. Br. described by Robert Brown in 1819 (Marohasy and Forster 1991). The common name for *C. grandiflora* in Australia is rubber vine. In Madagascar it is referred to as Lombiry (J. Marohasy personal communication 1994), and in India, India rubber or Pulay (Polhamus *et al.* 1934).

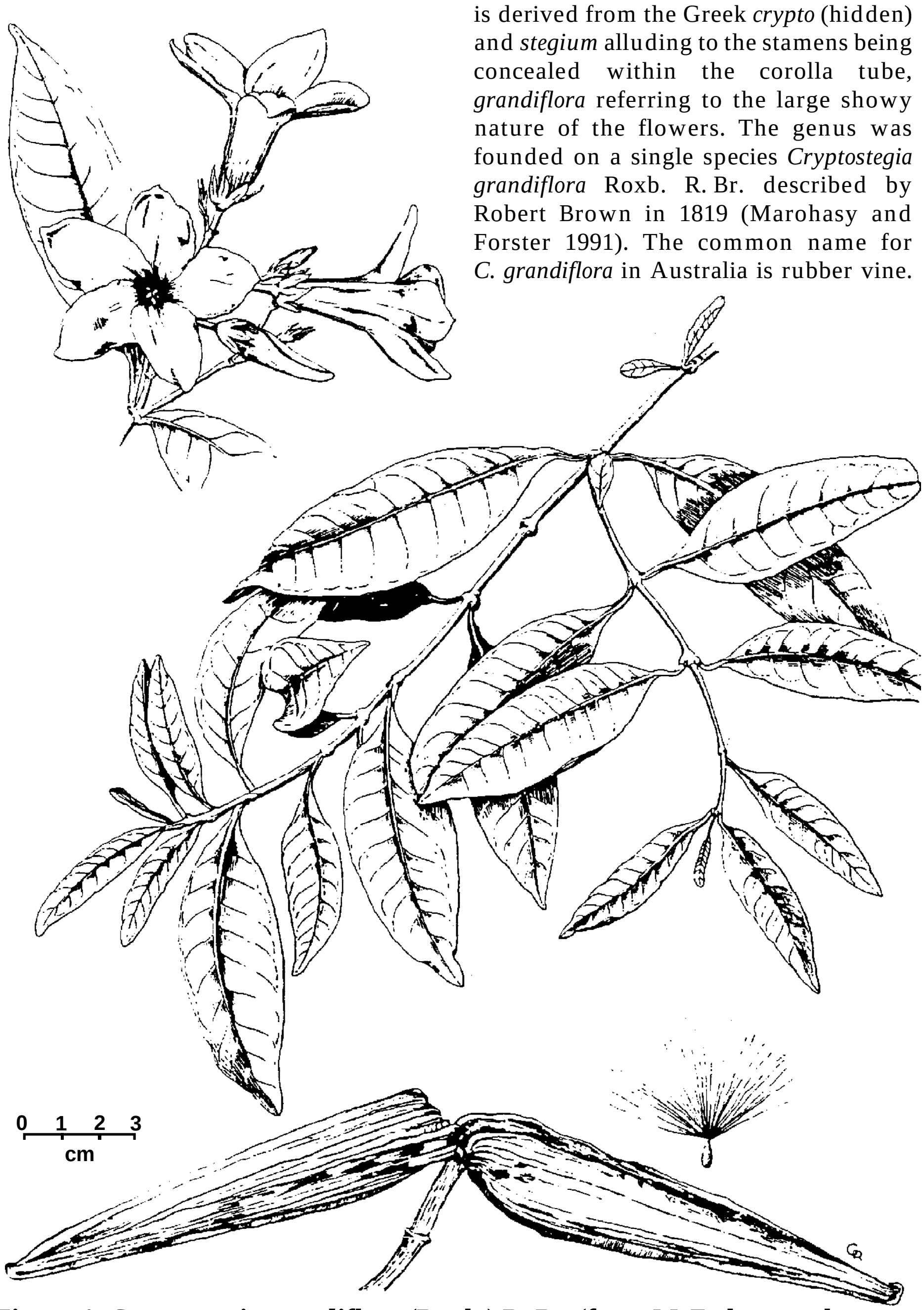

Figure 1. *Cryptostegia grandiflora* (Roxb.) R. Br. (from McFadyen and Harvey 1990).

Description

The following botanical description is based on Artschwager (1946) and Marohasy and Forster (1991).

Cryptostegia grandiflora (Figure 1) is described as woody liane or scrambling subshrub. Stems are slender, twining around each other or supporting plants. Rapid elongation of the tips in the growing season produces unbranched whip like stems up to 5 m long that quickly twine around any support that they contact. The mature bark is greyish brown with numerous lenticels and young stems have green smooth bark.

Cotyledons are small, foliar and entire. Leaf lamina elliptic to orbicular, up to 10 cm long and 6.3 cm wide, glabrous; 11–13 secondary veins per side of midrib; tip acute; base cuneate; petiole 7–20.8 mm long, 0.9–3 mm in diameter. Glossy green on upper surface, lighter underneath, veins, midrib and petiole often reddish purple, inserted as well separated (distant) pairs.

Cyme of one or two fascicles. Flowers large, 5–6 cm long, 5–8.8 cm diameter; pedicels 4.2–8.5 mm long, 3–6.2 mm diameter, glabrous. Calyx lobes lanceolate-ovate, 11.9–18.7 mm long, 5.6–9.8 mm wide. Corolla pale pink to white, lighter coloured internally, tube 1.9–4.5 cm long, 11.2–17 mm diameter; lobes 21–43 mm long, 13–22.5 mm wide; funnel shaped with five broad but pointed lobes. Corolline corona of 5 bilobed filaments in throat of tube; each lobe 10 mm long overall, bilobed portion approximately 8 mm long. Staminal column 2–3 mm long, 3–4 mm diameter; anthers 4–4.5 mm long, 3–3.5 mm wide. Translators obtuse, approximately 3 mm long and 1.5 mm wide. Style head conical, about 3.5 mm long and 2.5 mm diameter. Ovaries about 4 mm long and 2 mm wide.

Follicles fusiform-ovoid 10–15.4 cm long, 2.1–4 cm diameter; produced in opposite pairs diverging from the tip of a short common stalk, sharply 3-angled, tapering into a long beak. Seeds brown, 5.2–9.7 mm long by 1.6–2.8 mm wide, coma white, 18.9–38 mm long. Roots reddish brown externally, consisting of a mass of downward spreading robust secondary roots to depths of 12 m with thin fibrous feeding roots.

The two species of *Cryptostegia* can be distinguished easily as living specimens. The leaves of *C. grandiflora* have purple-coloured mid-ribs and petioles. The flowers are paler and larger than those of *C. madagascariensis*. The corolla glands in the flowers are pale pink and bifurcate, forming two narrow filaments (Figure 2).

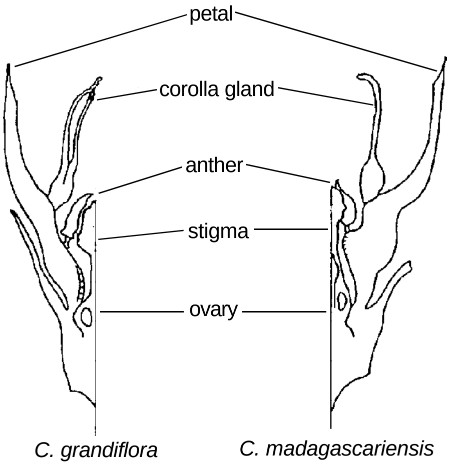

Figure 2. Comparative flower structure of *Cryptostegia grandiflora* and *Cryptostegia madagascariensis*, showing bifurcate corolla glands in *C. grandiflora* (from Curtis 1946).

The fruit is larger than that of *C. madagascariensis*. The leaves of *C. madagascariensis* never have purple coloration in the petiole and mid-ribs, and the corolla glands are deep pink and single (Polhamus *et al*. 1934).

Putative hybrids of *C. grandiflora* and *C. madagascariensis* occur very occasionally in the region of Toliara, Madagascar where their distribution is sympatric. They may be distinguished by the intermediate floral morphology, most notably the lanceolate-obtuse translators approximately 2.5 mm long and 1.5 mm wide and the filaments being fused for about twice the length of those in *C. grandiflora* (Marohasy and Forster 1991).

Polhamus *et al*. (1934) described an interspecific hybrid which was developed for horticultural purposes in Florida.

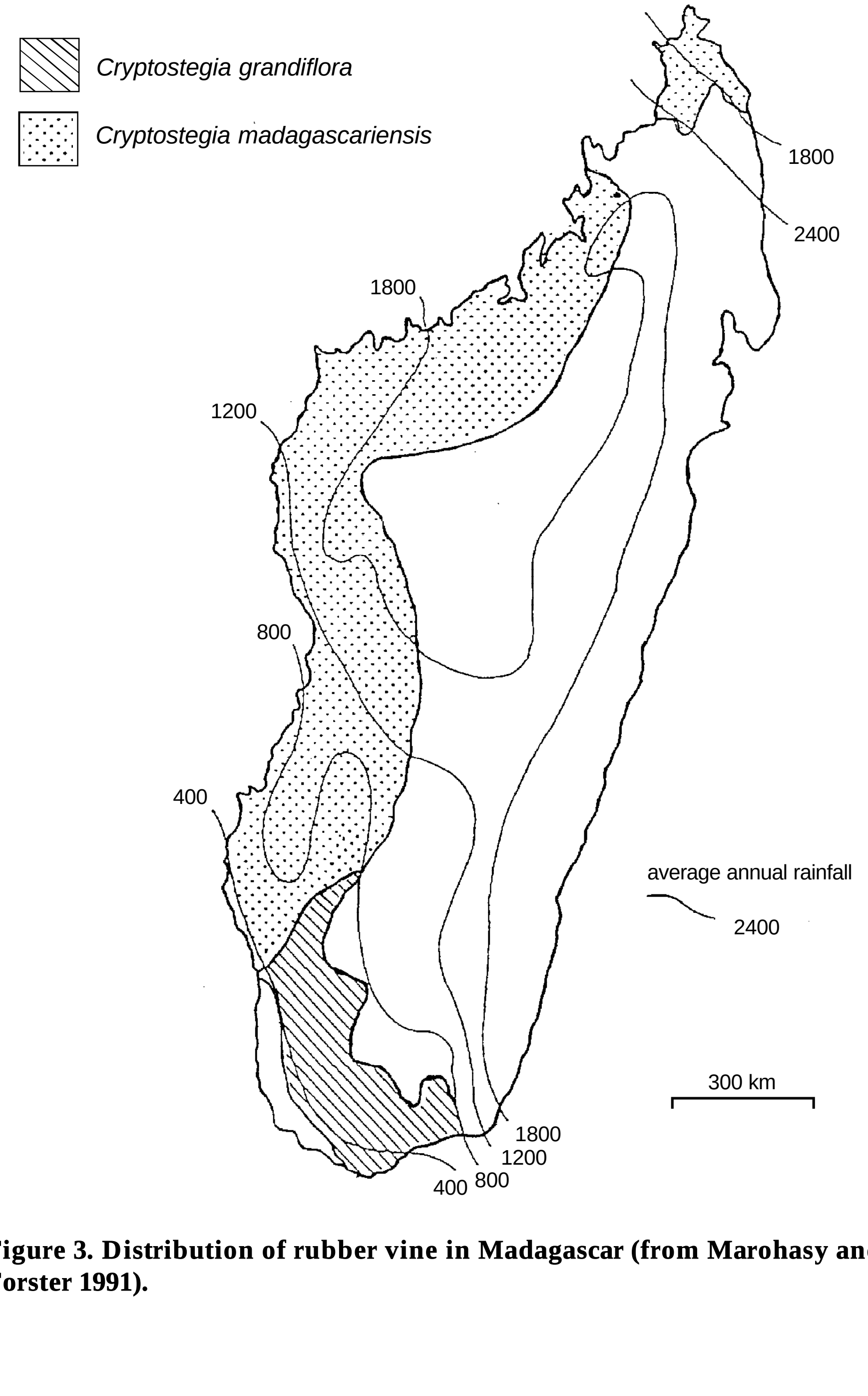

Figure 3. Distribution of rubber vine in Madagascar (from Marohasy and Forster 1991).

History

Rubber vine was reported from the Brisbane Botanic Gardens and Bowen Park, Brisbane in the late nineteenth century (Hill 1875, Bailey 1885). Early in the twentieth century it was recognised as a weed in the Townsville and Rockhampton areas of northern and central Queensland (White 1917). Rubber vine was introduced to the Charters Towers and Ravenswood mining districts in north Queensland during their early settlement (Hubble and Keogh 1942), and these became foci for dispersal (Dale 1980). By 1944 rubber vine infested a total area of 1200 ha in the districts around Ravenswood, Charters Towers, George-town and Rockhampton (Anon. 1944). Unsuccessful attempts were made to eradicate rubber vine from a public reserve at Rockhampton at this time.

Early interest in rubber vine as a source of rubber was reported by White (1923). Interest was renewed during the second world war, both in Australia (Anon 1944) and in Haiti (Curtis 1940, Symontowne 1943), but the process was not viable because of the low yield. During the 1980s rubber vine was promoted unsuccessfully as a potential source of oil (Queensland Graingrower September 1980).

Rubber vine has been deliberately planted in various other countries, mainly as an ornamental or because of its perceived economic potential as a source of rubber. It has become naturalized or weedy in Mexico, central America, the drier West Indian islands, New Caledonia and Australia (McFadyen and Harvey 1990).

Earliest records for countries outside its native range are: Haiti 1912 (Symontone 1943), Florida 1904, India prior to 1856, Mexico prior to 1900 (Polhamus *et al.* 1934). Jenkins (1943) reported rubber vine from most tropical countries.

Distribution

Madagascar

The two species of *Cryptostegia* are distributed along different parts of Madagascar's north to south wet to dry rainfall gradient. *C. grandiflora* occurs in drier south-western Madagascar. *C. madagascariensis* occurs in the wetter parts of north-western Madagascar (Figure 3) (Marohasy and Forster 1991). There is a zone of overlap of the two species less than 50 km wide situated between the Onilahy and Mangogy rivers (J. Marohasy personal communication, 1995).

Australia

In Australia, *C. grandiflora* is confined to tropical and subtropical Queensland, where it grows mainly in areas with an annual rainfall between 400 and 1400 mm

(McFadyen and Harvey 1990) (Figure 4). Major infestations have developed along watercourses (Dale 1980).

Habitat

Climatic requirements

Rubber vine's natural habitat is in arid regions (Knight 1944, Curtis and Blondeau 1946, J.J. Turnour unpublished results 1987), but it is most abundant on watercourses or locations with a high water table (Curtis and Blondeau 1946, Siddiqui and Mathur 1946, Sen 1968).

In Queensland, in areas with higher annual rainfall the plant is capable of spreading into a wide range of open habitats, being more luxuriant in moister sites (Humphries *et al.* 1991). In drier regions the plant is restricted to areas where it can access groundwater (Dale 1980).

Rubber vine is intolerant of shade (Beckett *et al.* 1934). Polhamus (1934) found that shading of plants slows growth, and under natural conditions the species is limited to open areas and the margins of forested areas.

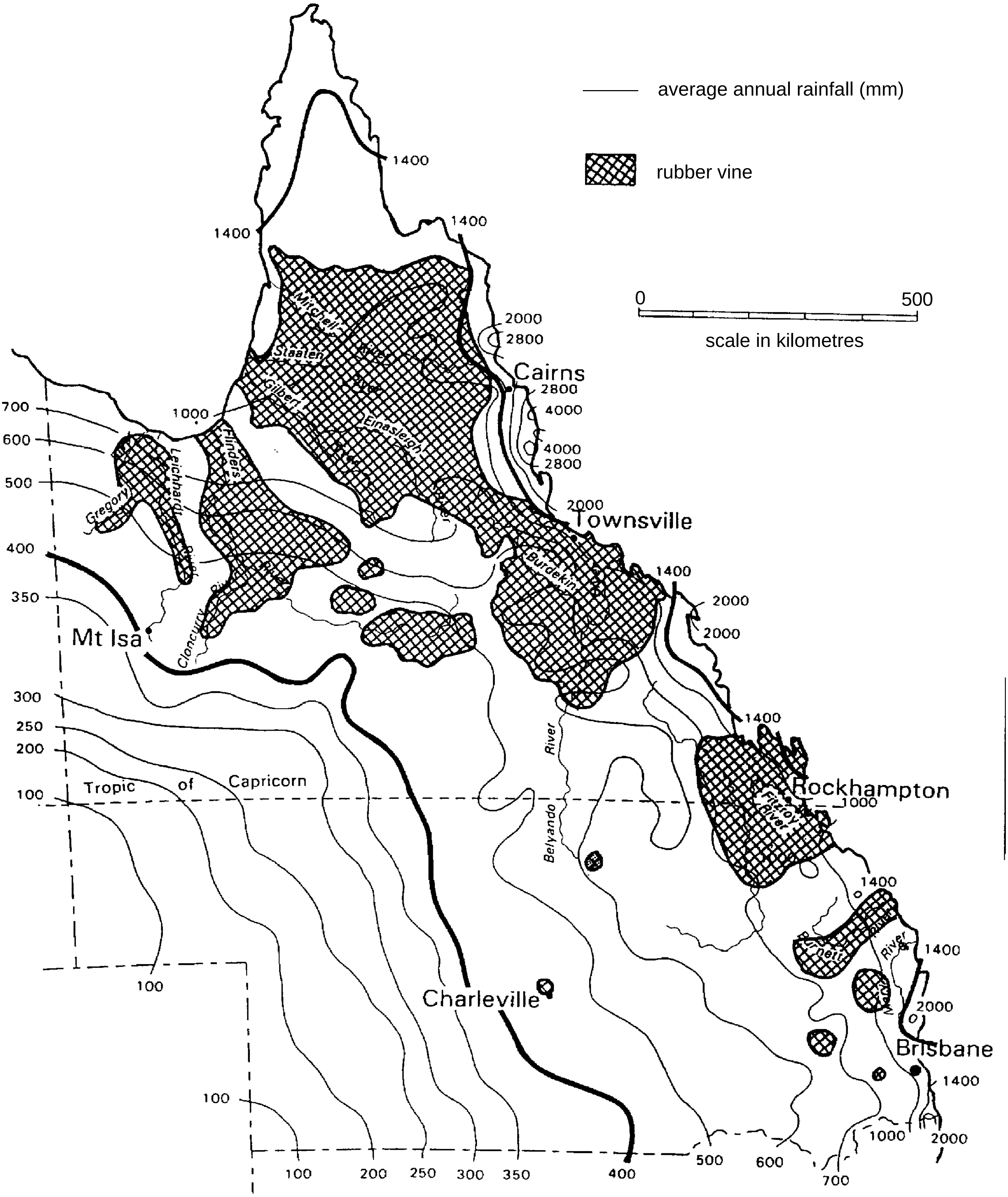

Figure 4. Distribution of rubber vine in Queensland (McFadyen and Harvey 1990).

In Queensland rubber vine climbs over native vegetation to reach full light, but it does not occur on the wet tropical coast probably due to the competition of other plants. While rubber vine has the ability to tolerate extremes of temperature (Polhamus 1962, Siddiqui and Mathur 1946, Nath 1943), maximum and minimum temperatures and relative humidity affect its growth (Nath 1943). Stem dieback supposedly results from frost damage (Beckett *et al.* 1934). However, this has never been observed at Gatton in south eastern Queensland where frosts are common and moderately severe in some years. In north Queensland, high temperatures combined with low summer rainfall may cause the plant to shed its leaves but no major damage is caused.

Chippendale (1991) mapped the potential distribution of rubber vine in Australia on the basis of climatic suitability as determined by locations where the plant is already established (Figure 5). The predicted distribution, comprising 20% of the area of northern Australia, takes no account of soil suitability. Allowing for unfavourable habitats, e.g. the wet tropical coast or zones which are too dry, there is a potential for 32 000–160 000 km^2 of reasonably dense rubber vine within a total area of 1 600 000 km^2 which is climatically suitable (McFadyen *et al.* 1991).

Substratum

Rubber vine is tolerant of a wide range of soil types (Polhamus *et al.* 1934, Siddiqui and Mather 1946, Bonner and Galston 1947, Stewart *et al.* 1948). In Queensland, rubber vine grows on soils ranging from beach sands to heavy clay soils.

Pot trials carried out by Dale (1980) showed that soils with a high clay content gave the best rates of establishment. Blake (1942b), Hubble and Keogh (1942) and Dale (1980) suggested that the major factor affecting germination and establishment under field conditions was the degree of protection of seed on the soil surface. This could be provided by surface disturbance, natural mulching of clay soils, a litter layer and shading by shrubs. Further, Dale (1980) stated that rubber vine distribution is largely independent of soil type but is affected by the presence of leaf matter and the absence of fire.

Plant associations

Rubber vine invades and dominates several plant community types, including riverine forest, eucalypt woodland and vine thickets or 'dry rainforest', including those on limestone outcrops, recent basalt flows and coastal sand dunes (J.P. Stanton personal communication 1988). As a result, some of these communities could be largely degraded. Fauna living in such communities are also threatened. Rubber vine destroys the habitat of the greater glider *Petauroides volans* Kerr and the squirrel glider *Petaurus norfolcensis* Kerr (Chippendale 1991). Humphries *et al.* (1991) relate the disappearance of three species of birds, white-browed robins *Poecilodryas superciliosa* Gould, rufous owls *Ninox rufa* Gould, and Bower's shrike-thrush *Colluricincla boweri* Ramsay due to invasion by rubber vine at Big Mitchell creek north of Mareeba.

Growth and development

Morphology

Mature plants can assume two growth forms. As an unsupported single plant, rubber vine forms a rounded straggly shrub with one or a few main stems and several branches intertwined for support. In thickets or supported by other vegetation it forms a dense tangled mass, smothering vegetation up to 40 m above the ground. There are two types of stems, one type producing fruits and flowers, the other a whip, which when supported will grow to 4.25 m in one month (Symontone 1943). White latex flows freely from damaged roots, stems, leaves and unripe pods.

Symontone (1943) described the growth rate of the plant when water was not limiting: seedlings emerged in three days, reaching 3.8 cm in one month, 11.4 cm in two months, 30–35 cm in three months, 152 cm in five months, and 365–425 cm at one year. He recorded the longest unsupported stem at 508 cm; rapidly elongating stems could grow 10 cm per day.

Density

No detailed studies of the factors affecting density have been carried out. The densest areas are found where water is readily available. Plant density decreases with distance from the seed source. On the basis of observations in the field in Queensland and impact of the plant, Vitelli (1992a) defined density categories as: heavy = greater than 2000 plants ha^{-1}, medium = 100 to 2000 plants ha^{-1}, light = less than 100 plants ha^{-1}. Vitelli (1992b) has sampled densities up to 5000 plants ha^{-1}.

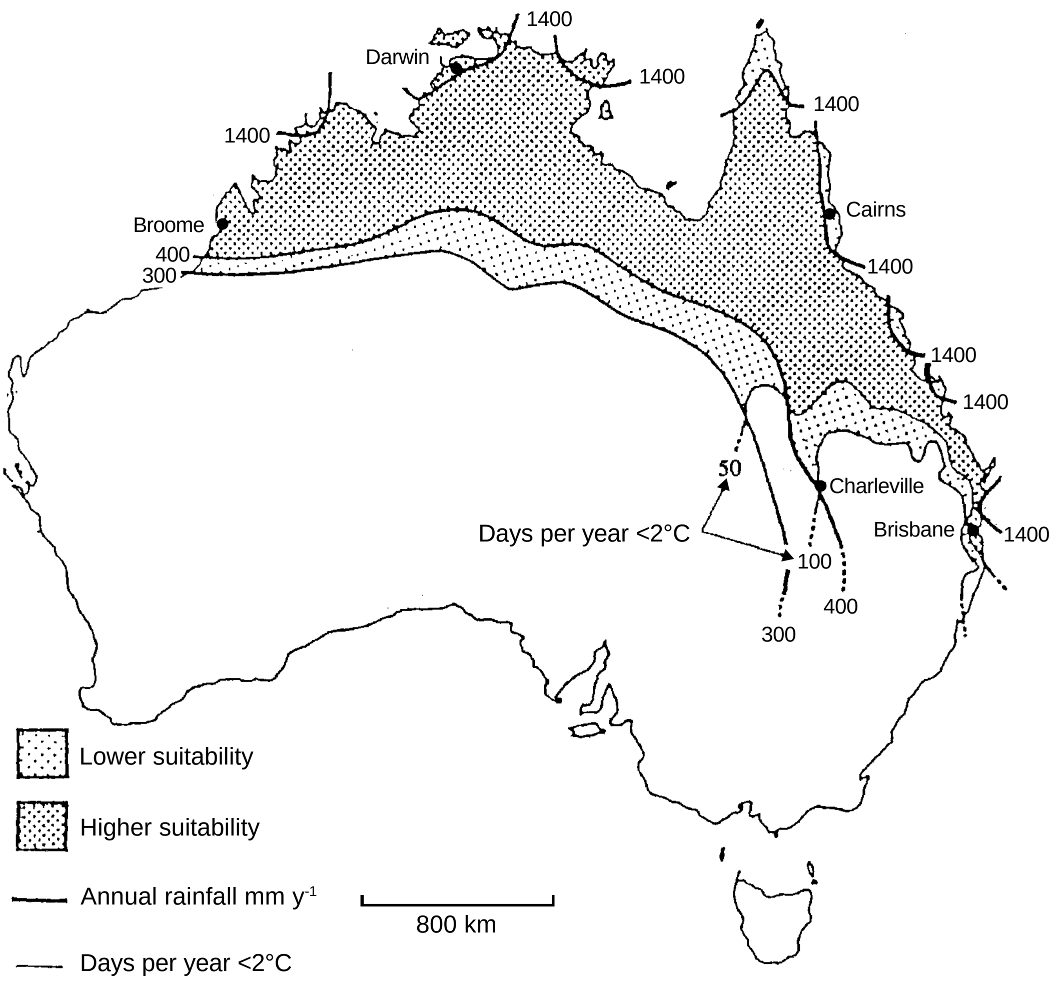

Figure 5. The potential distribution of rubber vine in Australia (from Chippendale 1991).

Perennation

The maximum life span of rubber vine is unknown. Dale (1980) encountered no dead mature plants in his extensive investigations.

Physiology

Water supply to the plant is the major factor influencing growth rate. Under cultivation, maximum growth rate is obtained with a total of 1500–2000 mm of precipitation annually (Polhamus 1962, Griffith 1944). At Charters Towers the most vigorous growth occurred where the moisture supply to the plant was most favourable irrespective of soil type (Hubble and Keogh 1942). Curtis (1946), however, stated that high rainfall and acid leached soils combine to cause stunted growth or prevent growth altogether. According to Dale (1980) this may be due in part to the increased competition and shading normally associated with higher rainfall. Plant size appears to be directly related to availability of water, absence of fire, and obviously, age. However, seasonal temperatures appear to play an important part, as plants at Gatton in southeast Queensland are of small stature compared to those growing further north.

At seasonally dry sites transpiration is reduced by leaf loss as soil moisture levels are depleted. Plants which lose their leaves in the dry will reshoot rapidly following even small falls of rain. However, such stress results in lower seed production (Dale 1980). On the other hand, plants on permanent water in north Queensland appear to suffer minimal leaf loss during the dry season.

Harvey (unpublished results 1988) concluded that rainfall was not an important controlling factor in the carbohydrate economy of rubber vine. Rather, carbohydrate metabolism appeared to be positively correlated with seasonal fluctuations in daylength and temperature. Accumulation of starch in the stem and the root begins abruptly in autumn, apparently when daylength drops below 12 hours. Depletion of starch reserves in winter, spring and summer is associated with maintenance, then mobilization of reserves for growth over spring and summer.

Phenology

The main period of growth coincides with the summer wet season. However, unless drought conditions prevail, fresh shoots appear on the stems in spring. Foliar growth ceases in late summer, unless stimulated by damage.

Rubber vine can flower at all times of the year if temperature and water are not limiting. In Haiti the plant flowers at the same time each year, but maximum fruit production depends on the rainfall distribution, with most pods being produced two months after rainfall peaks. Ripe seed is present during spring to early summer (Curtis 1946). Flowering in Queensland follows a similar pattern (Dale 1973). Flower production has two peaks, with the highest numbers in the summer peak and lower numbers in autumn.

Flowering virtually ceases in winter. Ripe seed is present at the end of the dry season and is released from pods before the onset of the following wet season. In Haiti, fruit production appeared to be closely correlated with rainfall (Curtis 1946).

Plants may make unseasonal growth and flower in response to damage, but they do not set fruit out of season. A plant which can flower all year round but which sets seed only after substantial rainfall has a clear advantage in a monsoonal climate where long dry periods occur (Dale 1980).

Reproduction

Floral biology

In Haiti rubber vine flowers in 5–7 months. Curtis (1946) provides a detailed account of the flowering process. 'The large and showy flowers are borne at the branch tips in dichotomous cymes. The terminal flower is the first to open and is followed by a pair of flowers each on a separate branch originating below the first flower. The branches continue to bear single flowers with the flowers on the two branches opening in pairs. Typically the pairs are separated by six days in anthesis. The average number of pairs is seven, thus giving an average total of 15 flowers per infloresence. The branches are conspicously jointed between successive flowers. They possess abscission layers at each joint. The glands within the corolla tube of *C. grandiflora* converge at the tips. The flowers remain open for 24 hours or less with the majority falling within 14 hours whether they are pollinated or not. This abscission results in the dropping of only corolla, stamens, stigma and style. The ovaries, calyx and receptacle remain attached for an additional 80 hours in non-pollinated flowers.'

Flowering branches set from 20–50 blossoms of which 10–50% set 300–350 seeds per pod (Symontowne 1943).

Pollination

Rubber vine is entirely insect pollinated, but only a limited number of insects are capable of pollinating the flowers because of the structure of the flower (Knight 1944). Blake (1942a) found no evidence of pollination of flowers in Queensland, but viable seed is produced in all areas that have been sampled (Dale 1980). In Madagascar, scarab-like beetles were seen visiting flowers and thrips were also present inside the corolla tubes (J.J. Marohasy personal communication 1994). There is no published information about insect pollination of species in the Tribe Periplocoideae (P. Forster personal communication 1995).

Seed production and dispersal

Little work has been done on the production of seeds and fruit in Australia. Curtis (1946) found that at 1100 plants ha^{-1} each plant produced 15 fruits per annum, while at densities of 12 000–29 000 plants ha^{-1} each plant produced one fruit. Fruit development took 173 days and mean seed weight was 9 mg with an average of 668 seeds per fruit. Seed production at Charters Towers was 340–380 seeds per fruit (J. Vitelli unpublished results 1987).

When mature, the fruit follicle splits longitudinally along the upper face, allowing the seed plumes to be opened by the wind and the seed carried off. In the northern part of rubber vine's range in Queensland, strong south-easterly winds and 'whirly winds' are common late in the dry season when the pods are splitting and could provide efficient wind dispersal (Dale 1973). While some seeds are blown several hundred metres (Dale 1973), most seeds are found close to the parent plant (J. Vitelli personal communication 1994). For a wind borne seed the weight is comparatively high (10 mg) and dispersal would be limited (Sen 1968).

Water is also a major means of seed dispersal. Seed with the plume attached can float in water for a considerable time. Seed can tolerate prolonged periods of immersion in saline water with little effect on viability (J. Vitelli personal communication 1994). While rubber vine is not found growing in the same soils as mangroves, it will survive in very close proximity to them. Therefore effective dispersal by sea water could be a possibility if the seed were deposited high on the land.

Seed is probably spread by animals which inhabit rubber vine areas though little is known about this. Human activities, particularly where machinery and vehicles are involved, can also be an important means of dispersal.

Physiology of seeds and germination

Rubber vine seed is comparatively short lived. High viability may be maintained for about three years in the laboratory, but less than one year on the soil surface. In the absence of rain, buried seed will probably remain viable for about 6–8 months (Scanlan 1992). Dale (1980) found that germination rates on bare soil surface varied considerably, the highest rates being on clay soils. However, much of the seed produced would probably perish after landing in unsuitable sites for germination (Dale 1973).

Spread of rubber vine is therefore dependent on continuing seed production from year to year rather than a long lived seed bank.

When ripe, seeds are dry and shrivelled, an advantage for wind transport. There appears to be no dormancy mechanism. Sen (1968) (cited in Dale (1980)) found that seeds were primarily dark germinating, although at lower temperatures some germination occurred in continuous illumination. Germination was most rapid in darkness at temperatures from 25–30°C, and was slower under light at higher temperatures. In Dale's own studies, germination on filter paper reached 100% in three days under optimum conditions.

Vegetative propagation
Asexual propagation has been used in plantations (Polhamus *et al.* 1943). Almost any section of a stem bearing dormant buds at each node appears capable of growth. Vegetative propagation in nature is rare, but may occur when long stems are partially buried by floods (Caltabiano 1973).

Population dynamics

Rate of increase
Caltabiano (1973) stated that there were in excess of 120 000 ha infested north of Bowen and that this area was estimated to be increasing at the rate of 1–3% per annum.

McFadyen *et al.* (1991) provided a time course of spread and potential distribution based on three estimates over time of the area of rubber vine in Queensland (Table 1).

The 1989 estimate of 6000 km^2 is 2% of the 300 000 km^2 affected, representing reasonably dense infestations adjacent to rivers and creeks (Chippendale 1991). This estimate is felt to be conservative (J. Chippendale personal communication 1991).

Importance

Detrimental
Rubber vine is both an agricultural and an ecological problem. It contains poisonous cardenolides (cardiac glycosides) (Aebi and Reichstein 1950, Doskotch *et al.* 1972).

Table 1. Time course of spread of rubber vine in Queensland (Anon. 1944, Caltabiano unpublished data 1972, Chippendale 1991).

Year	Area (km^2)
1917	<1
1942	12
1972	2025
1989	6000

Feeding tests showed the leaves to be toxic to cattle, horses, goats and sheep, with horses being particularly susceptible (McGavin 1969, Everist 1974). Extracts of the stems are similarly toxic (Thorp and Watson 1953), and the plant has been implicated in human as well as animal deaths (Perrot and Raymond-Hamet 1932). Fortunately rubber vine is unpalatable and seldom eaten, so that deaths are few. (McGavin 1969, Everist 1974, McFadyen and Harvey 1990).

Rubber vine seriously hinders the day-to-day management of cattle which can hide in dense thickets along watercourses. Mustering costs are almost doubled and cattle are lost, which, apart from the direct economic loss, makes disease control and maintenance of herd quality unattainable. In addition, there is the direct loss of pasture on better soils where rubber vine competes directly with pasture grasses, dense infestations reducing carrying capacity by nearly 100%.

An economic study by Chippendale (1991) estimated the annual cost of rubber vine to the cattle industry alone to be in excess of $A8 million.

Rubber vine also seriously damages native plant communities (J. Stanton personal communication 1986). A report on plant invasions of Australian ecosystems (Humphries *et al.* 1991) regarded rubber vine as 'the most critical species of any identified by this study'. Its continued spread through semi-arid monsoonal vegetation is threatening gallery forests and dry rain forests in particular (McFadyen *et al.* 1991).

The potential for the plant to spread westward into the Northern Territory has prompted a proposal to establish a 100 km wide rubber vine free buffer zone extending from the Northern Territory border to 139°E, and from the Gulf Coast to 21°S (Fuller 1993).

Beneficial
Utilization of rubber vine as a potential source of rubber and oil has been investigated but has not proved economical.

Legislation

In Queensland rubber vine is a declared plant under the provisions of the Rural Lands Protection Act (1985–88). In the shires to the north and west of Miriam Vale it is declared as category P3, requiring that the area of infestation must be reduced. Elsewhere it is declared in category P2 and must be destroyed. Rubber vine is also declared noxious in the Northern Territory as a class C weed, meaning that it should not be introduced. In Western Australia rubber vine is classed as a P1 or P2 weed over the whole of the state.

Weed management

Herbicides
Investigations of herbicides for control of rubber vine have been carried out by Queensland Department of Lands over the past two decades (McFadyen and Harvey 1990, Vitelli *et al.* 1994).

McFadyen and Harvey (1990) reported that rubber vine was susceptible to a wide range of herbicides, with results being dependent on formulation, method and timing of application. Scattered plants could be treated by basal bark applications of picloram, triclopyr, or 2,4-D esters or mixtures of these or by application of hexazinone with a spot gun. Aerial or ground application of tebuthiuron pellets was also effective on appropriate soil types where non-target plants were not at risk. For foliar application, the best results were obtained with picloram / 2,4-D as the triisopropanolamine salt or dicamba as the dimethylamine salt.

The most effective of the phenoxy acids tested was 2,4-D, with ester formulations being more effective than salt formulations (Harvey 1987). McFadyen and Harvey (1990) concluded that 2,4-D was the most environmentally acceptable herbicide owing to its short half life and low toxicity to most native woody species. Widespread application of dicamba, picloram, hexazinone or tebuthiuron was not recommended because of their potential to damage non-target species.

Vitelli *et al.* (1994) tested the response of actively growing mature rubber vine plants 1.5–2.5 m high to foliar applications of various herbicides in water. They found that picloram / 2,4-D, imazapyr, metsulfuron, picloram / triclopyr and dicamba were not significantly different in efficacy, all giving kills of 91–100%. Formulations of 2,4-D gave relatively poor results with a maximum kill of 51% for the ethyl ester, 18% for the amine salt.

G.J. Harvey (personal communication 1994) and Vitelli *et al.* (1994) showed that foliar applications of herbicides must be timed to coincide with active periods of growth to obtain best results. The optimum time for application is March / May, but it is critical that the plants be actively growing and not water stressed, yellowing or bearing pods.

Harvey (1988) proposed that seasonal efficacy of herbicides was associated with physiological changes in the carbohydrate economy of rubber vine. Indeed, foliar applications of 2,4-D were only effective in the autumn.

Herbicides currently recommended for the control of rubber vine are listed in Table 2.

Methods of application. Vitelli (1992c) suggested that for best results from foliar overall spray applications, a suitable wetting agent must be used, plants should be thoroughly sprayed to the point of run-off, spraying should be avoided when temperatures are above 35°C, and that foliar spraying is most effective on plants less than 2 m high. Large plants with a stem diameter greater than 8 cm diameter would not be killed.

Aerial trials by Vitelli (1992d) showed that picloram / triclopyr was the most cost efficient herbicide. Carrier volume had a significant effect on mortality. In these trials, 2,4-D butyl ester did not kill any plants.

For basal bark application, plants should also be actively growing. Herbicides should be mixed with diesel distillate and sprayed completely around the base of the plants to a height ranging from 10–100 cm above ground level, depending on stem diameter. Stems greater than 8 cm in diameter should be treated by the cut-stump method. Plants should be cut off as close as possible to ground level and the cut surface and immediately saturated with herbicide. Treatments can be made at any time of the year (Vitelli 1992e).

Strategies. Rubber vine infestations are so vast that overall control by herbicides is impossible. Vitelli *et al*. (1994) commented that the cost of spraying all known areas of rubber vine once, would be $A300–1300 million for herbicide purchase alone!

Scanlan (1992) stressed the importance of controlling infested areas to protect clean land, describing such outlays as 'insurance'.

Herbicides are indicated mainly for the elimination of scattered and isolated plants to prevent further development of dense infestations. However, herbicides may have a role as part of integrated management systems for the control of dense vine. Vitelli *et al*. (1994) state that the efficiency of herbicide applications must be high, i.e. >90% total kill, to reduce costs by minimizing the number of applications necessary.

Rubber vine control should be undertaken only after land managers have devised an integrated program designed to achieve the best results for the particular location with the capital and resources which are available.

Vitelli (1992a) suggested the following strategies for controlling infestations of varying densities:

i. Scattered infestations of up to 100 plants per hectare should be the first priority in a control program. These are most efficiently killed using either basal bark or cut stump application of herbicides.
ii. Medium density infestations of 100–2000 plants per hectare can best be controlled by the same techniques plus foliar applications of herbicides. A follow up treatment may be necessary.
iii. Dense infestations of over 2000 plants per hectare require an integrated management system specifically designed for the property, available equipment and expertise. A system might include fencing and destocking to increase fuel loads for burning off, planting of improved pasture species, as well as herbicidal and mechanical treatments.

Foliar spraying of dense areas must be followed up by burning off after 9–12 months, respraying when leaves begin to develop, or basal bark spraying isolated plants. Fire is the preferred follow up treatment but this requires the exclusion of stock to allow fuel build up.

Foliar application using ground equipment should only be considered on scattered to medium infestations. Heavy infestations along creeks are probably best treated with helicopters. However, care should be taken to minimize damage to non-target plants.

Applications of tebuthiuron should be in accordance with considerations of soil type, slope and damage to non-target plants. Aerial application is most cost effective on large dense infestations (e.g. 6500 plants per hectare)

Other treatments

Fire is the most economical tool for the control of dense rubber vine infestations, the main effects being reduction of the bulk of mature plants and destruction of seedlings and above ground seed (Vitelli 1992b). The trend towards reduced frequency of fires has allowed rubber vine to invade areas where its establishment was previously prevented, as regular fires prevent the spread of rubber vine away from water courses (Dale 1980). Dale (1980) concluded that the use of fire has to be balanced against any undesirable effects including changes in the composition of the pasture, loss of nutrients, increased erosion and reduced amounts of pasture available for stock. Management of stocking rates will be required to ensure that there is sufficient fuel to support a fire and to restrict it to the area to be burnt off. Dale (1980) found that mature plants with an accumulation of fuel at the base were completely killed while the remainder were killed back to ground level. Vitelli (1992b) found that between 50–70% of plants were killed in pastures whereas less than 5% were killed within creeks because of lower fuel loads.

Mechanical control is recommended for medium to dense infestations where the terrain is suitable. The density of infestations can be reduced by the use of heavy discing, cutter bars, or blade ploughing from June to September. Apart from removing the bulk foliage and stems, bulldozing usually kills about 10% of plants and must be followed by other control methods to deal with regrowth (Vitelli 1992f).

Slashing with a heavy duty machine fitted with blunt blades gives very effective

Table 2. Current herbicide recommendations (Queensland Department of Lands Pestfact 1994).

Herbicide	Method of application	Dilution[A] or rate
2,4-D butyl ester		
600 g L^{-1}	foliar spray	1:50 w
600 g L^{-1}	basal bark	1:40 d
600 g L^{-1}	cut stump	1:40 d
600 g L^{-1}	aerial	5–7 L ha^{-1}
2,4-D amine salt		
500 g L^{-1}	cut stump	1:50 w
triclopyr butyl ester		
600 g L^{-1}	basal bark	1.7:100 d
600 g L^{-1}	cut stump	1.7:100 d
dicamba	foliar spray	1:100 w
metsulfuron methyl	foliar spray	15 g per 100 L w
imazapyr	foliar spray	0.4 L per 100 L w
picloram / 2,4-D		
5+20 g L^{-1}	foliar spray	1:100 w
picloram / triclopyr		
10+20 g L^{-1}	foliar spray	0.35 L per 100 L w
10+20 g L^{-1}	aerial	1.5–3 L ha^{-1}
velpar	soil application	1–4 mL $spot^{-1}$
tebuthiuron	soil application	1.5 g m^{-2}
tebuthiuron	aerial application	7.5–15 kg ha^{-1}
power kerosene	cut stump	straight

[A] Diluents d = diesel distillate, w = water control by shattering and killing some of the bigger stumps. All mechanical treatments need to be followed up in an integrated control program (Vitelli 1992f).

Natural enemies

Surveys of natural enemies by Australian entomologist J. Marohasy (née Turnour), based in Toliary in south east Madagascar from 1985 to 1988, revealed several potentially useful agents.

All but one of the insects, a leaf feeding caterpillar *Euclasta whalleyi* Popescq-Gorj and Contantinescu, Pyralidae, proved to be insufficiently host specific (McFadyen and Harvey 1990). The other insects included a diaspid scale *Hulaspis* sp. whose host range included a species within the Sterculiaceae, the potentially very damaging margarodid mealybug *Steatococcus* sp. which fed on many species within the Asclepiadaceae, a hawk moth *Nephele densoi* Keferstein which laid eggs and developed on native *Ficus* species, and a bud galling midge *Shizomyia* sp. suspected of attacking other species in the Asclepiadaceae could not be reared in quarantine and thus was never tested.

The moth *Euclasta whalleyi* is restricted to plants in the sub-family Periplocoidae. While there are no important crop plants or ornamentals in this group in Australia there are two native species of *Gymnanthera, G. nitida* R. Br., a fairly common vine occupying similar habitats to those of rubber vine across northern Australia, and *G. fruticosa* Wilson, a shrub from near Alice Springs. On the basis that the threat of extinction of *G. nitida* was far greater from rubber vine than from *E. whalleyi* and that because of its location *G. fruticosa* was at minimal risk from *E. whalleyi*, permission was given in 1987 for release of *E. whalleyi* in the field. Between 1988 and 1990 from Rockhampton to Cape York large numbers of moths and larvae were released. The moth failed to become established at the majority of release sites but recently has been recovered at a few in the Charters Towers district (M. Trevino personal communication 1995). At this stage its impact on the plant is unclear.

Also between 1985 and 1988 short surveys were made by plant pathologist H. Evans from the Commonwealth Institute of Biological Control. The rust fungus *Maravalia cryptostegiae* (Cummins) Ono is the most prominent and possibly the most damaging of the parasites naturally associated with rubber vine in Madagascar (R. McFadyen unpublished report 1985). Infections of the leaves cause significant defoliation of the plant during the growing season.

Detailed host testing showed that the rust was highly specific, being fully sustained only on *C. grandiflora*, *C. madagascariensis* and producing fertile sori on the partially resistant, closely related *Gonocrypta greveii* (Evans and Tomley 1994). During laboratory host testing in the United Kingdom inoculations with very heavy spore loads resulted in weak infections on *Cryptolepis grayi* P.I. Forst, a closely related Australian native plant in the sub-family Periplocoideae also classified as partially resistant. This plant was considered not to be at risk and permission to release the rust in the field was given in early 1993. Large scale field releases of the rust were made during the 1993/1994 and 1994/1995 summer seasons. Recoveries have been made at several sites. However, it is too early to claim that the rust has permanently established. The ultimate effect of the rust on the rubber vine population at best will be a weakening of the host so that it is less invasive.

Other pathogens, including *Phaeoisariopsis* sp., *Colletotrichum gloeosporioides* (Penzig) Penzig & Sacc., *Phomopsis* sp. and *Pseudocercospora* sp. were also found during surveys in Madagascar (H. Evans, unpublished report). These fungi may be considered for further testing in the future depending on results obtained with *M. cryptostegiae*.

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