

# Feasibility of biological control of African Boxthorn

## *Lycium ferocissimum*



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## Contact and business details

### Australis Biological

Director: Dr Robin Adair

PO Box 151

Bittern

Vic 3918

[robin.adair@australisbiological.com.au](mailto:robin.adair@australisbiological.com.au)

[www://australisbiological.com.au](http://www://australisbiological.com.au)

Tel: 0431576427

ABN: 30-464-924-818

## Feasibility of biological control of *Lycium ferocissimum* (African Boxthorn)

### Executive Summary

*Lycium ferocissimum* (African Boxthorn) presents considerable challenges for effective control using chemical and physical methods of suppression. In sensitive natural ecosystems, management options are limited and may incur off-target damage. In agricultural habitats, a broader range of management options are available, but treatment incurs considerable costs and persistent application is often required. The negative impacts of *L. ferocissimum* on environmental and agricultural values are considerable (decline in biodiversity values, reduced productivity, host to pests and pathogens) and greatly outweigh positive attributes (provision of habitat in degraded areas).

The family Solanaceae is cosmopolitan and includes a number of plants of considerable economic importance, such as potato, tomato, capsicum, and eggplant. *Lycium* are contained in the tribe Lycieae and in the subfamily Solanoideae. Australia has one native *Lycium* species (*Lycium australe*), but several exotic *Lycium* are naturalised. The relative taxonomic isolation of *L. ferocissimum* in Australia, together with its negative impact profile, makes the species a suitable target for biological control.

Few organisms are associated with *L. ferocissimum* in Australia, and these are nearly always generalist pests or casual visitors. Although the natural enemies of *L. ferocissimum* in its native habitat (South Africa) have not been adequately surveyed, museum records and taxonomic treatments indicate specialist feeders occur on the host and have potential for biological control in Australia. A rust fungus (*Puccinia rapipes*), several leaf-feeding tortoise beetles (*Cassida* spp.) and phloem-feeding bugs (*Schuhistes* spp.) are potential biological control candidates. Structured entomological and pathogen surveys in South Africa are likely to reveal further potential biological control candidates.

## Recommendations

- ❖ Proceed with an application for formal nomination of *L. ferocissimum* as a target for biological control in Australia as the species has no conflicts of interest and causes significant economic harm.
- ❖ Undertake structured surveys for phytophagous organisms associated with *L. ferocissimum* in South Africa as the phytophagous census for the species is incomplete.
- ❖ Undertake further entomological and pathogen surveys on Australian populations of *L. ferocissimum* in spring and summer as winter sampling may have missed important records.
- ❖ Include surveys on the Australian endemic species *L. australe* in areas where sympatric distribution occurs as scant information is available on the phytophagous organisms associated with this closely allied species.
- ❖ Determine the genetic diversity of *L. ferocissimum* in Australia using molecular sequencing or fingerprinting techniques as no genetic information is currently available on the species including ploidy levels, and degree of intra- and inter-population variation.
- ❖ Determine the region of origin of *L. ferocissimum* in South African using molecular methodologies as this will assist in the location of biological control agents suitable for infestations in Australia.
- ❖ Assess potential conflicts in relation the future commercial use of *Lycium* species, particularly *L. barbarum* (Goji Berry).

## Feasibility of biological control of *Lycium ferocissimum* (African Boxthorn)

### 1. Taxonomy

Class: Asteridae

Order: Solanales

Family: Solanaceae

Subfamily: Solanoideae

Tribe: Lycieae

*Lycium ferocissimum* Miers

Common name: African Boxthorn

Synonyms:     *Lycium macrocalyx* Domin  
                  *Lycium europaeum* L. (misapplied)  
                  *Lycium horridum* Thunb. (misapplied)



### 2. Description

A much branched, dense, woody glabrous shrub up to 6 m high and 3 m wide. Rigid and leafy, lateral branches ending in long spines, up to 15 cm long. Leaves glabrous, fleshy, elliptic to 4 cm long and 1.2 cm wide and often in clusters of 5-12; leaves sessile or shortly petiolate. Flowers funnel-shaped, bisexual, singular or paired at nodes, about 10 mm in diameter and 10-12 mm long, 5 merous. Petals white or pale purplish with a deeper purple throat, fragrant. Stamens 5, exerted (2-4 mm) beyond corolla tube. Flowers present most of the year, but mainly produced in summer. Fruit a 2-locular succulent berry, globular, to 1 cm wide, red when mature containing up to 70 dull yellow seeds.

### 3. Solanales and Solanaceae - classification and evolution

The order Solanales belongs to the core asterid clade or sympetalous lineage of flowering plants. The order appears to be most closely related to Lamiales and Gentianales. A phylogenetic tree for the Solanales is presented (Figure 1).

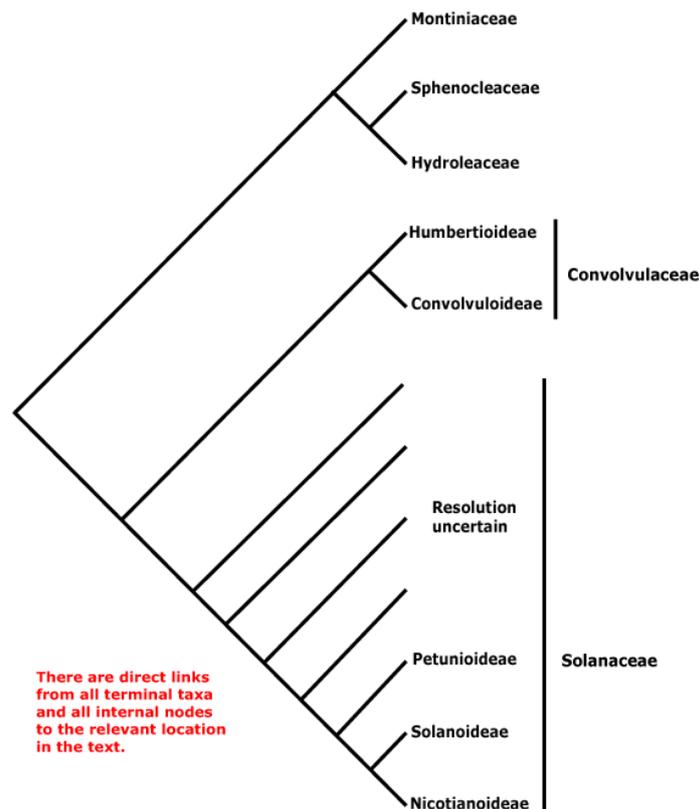


Figure 1. Phylogenetic topology for the Solanales showing the position of related families, the Solanaceae and three subfamilies. (After Stevens 2001: <http://www.mobot.org/mobot/research/apweb/orders/solanalesweb.htm>)

The Solanaceae is the largest family in the order and are a monophyletic group containing approximately 100 genera and 2,500 species (D’Arcy 1991; Olmstead et al. 1999; Hunziker 2001; Olmstead & Bohs 2007). Closely allied families are the Montiniaceae (woody species from Africa and Madagascar), Hydroleaceae (herbs to shrubs, tropical to warm temperate), Sphenocleaceae (annual herbs, pantropical) and the Convolvulaceae (herbs, lianas, trees, cosmopolitan).

The Solanaceae has a worldwide distribution and is present on all continents (except Antarctica) with the greatest diversity in the tropical and temperate regions of South America and Central America (Figure 2). In Australia, the family is represented by 25 genera (Appendix 1) and 322 species or subspecies where six genera and around 130 species are endemic, and 87 species are naturalised exotics. The Solanaceae has a New World origin, with perhaps 8-9 dispersal events to the Old World (Tu et al. 2010). The early-diverging clades in the family

are currently temperate or Andean in distribution, perhaps reflecting the original climatic preferences of the family (Olmstead 2013).

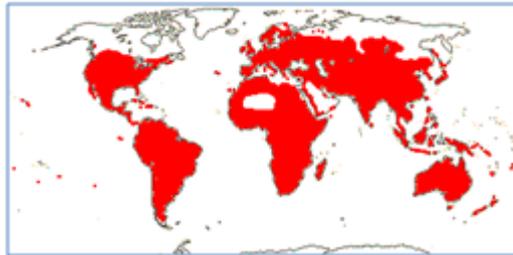


Figure 2. Distribution of Solanaceae (red). After Stevens 2001:  
<http://www.mobot.org/mobot/research/apweb/orders/solanalesweb.htm>

There are seven recognised sub-families within the Solanaceae, but there are substantial uncertainties about relationships between the major groupings. The subfamilies are: the Schizanthoideae (annual herbs, South America), Goetzeoideae (trees and shrubs, Greater Antilles), Browallioideae (*Cestrum*, North and South America), Schwenckioideae (annual herbs, South America), Petunioideae (herbs and shrubs, central and south America), Nicotianoideae (herbs, mostly Australian) and the Solanoideae (herbs to trees, world-wide, but rich in South America).

The Solanaceae includes economically cultivated species within the genus *Solanum*, notably potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*) and eggplant (*Solanum melongena*). Important related species include capsicum (*Capsicum annuum*), chilli (*C. frutescens*), ground cherries (*Physalis*), tobacco (*Nicotiana*) and a range of widely grown ornamental plants such as *Browallia*, *Brugmansia*, *Brunfelsia*, *Cestrum*, *Datura*, *Lycianthes*, *Nicotiana*, *Nierembergia*, *Petunia*, *Physalis*, *Salpiglossis*, *Schizanthus*, *Solanum*, *Solanandra* and *Streptosolen*. With the exception of tobacco (Nicotianoideae) and petunia (Petunioideae), most of the economically important genera are contained in the subfamily Solanoideae. *Lycium* also belongs to the Solanoideae.

#### 4. *Lycium* – phylogeny, classification and evolution

*Lycium* is one of the larger genera of the Solanaceae consisting of woody shrubs distributed throughout the temperate and subtropical regions of the world, but with a centre of diversity in the New World. There are approximately

21 species in North America, around 35 species in South America (Cabrera 1981, Bernadello 1986) and Africa, around 10 species in Eurasia, and one species in Australia (Figure 3) (Appendix 1).

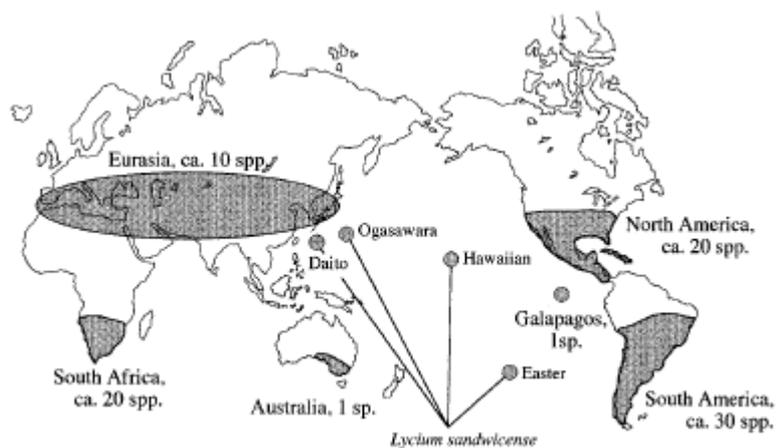


Figure 3. Distribution of *Lycium*. After Fukuda et al. (2001).

Despite weak conflicting evidence from ITS sequence data (Miller & Venable 2000; Miller 2002), molecular phylogenetic studies of *Lycium* (Fukuda et al. 2001; Levin & Miller 2005; Levin et al. 2007) conclude that *Lycium* is paraphyletic and needs to include the related monophyletic genus *Grabowskia* (Levin et al. 2011). There is little support for division into infrageneric sections within *Lycium* (Levin & Miller 2005). Within *Lycium*, there is a monophyletic group of old world taxa (Fukuda et al. 2001, Levin & Miller 2005) that are a well supported clade nested within a group of American species (Figure 4). In the evolution of the genus, it appears there was a single colonization event in Africa from the Americas with subsequent migration to Eurasia and Australia (Figure 5) (Levin et al. 2007). Similarly, all phylogenetic studies support a North American ancestry of the Hawaiian and Pacific Island species of *Lycium*.

Levin et al. 2007 used amplified exons of the nuclear GBSSI (*waxy*) gene to study evolutionary relationships within the tribe Lychieae, one of the few studies that include the Australian endemic species *L. australe* and *L. ferocissimum*. *Lycium australe* is in a clade with the southern African species *L. tenue* and *L. gariense*, which is nested within a well supported clade of twelve southern African species. This finding concurs with Levin & Miller (2005) using chloroplast



*trnT-trnF* data. Fukuda et al. (2001) also used chloroplast sequence data, and found that *L. australe* was within an Old World clade, but relationships within that clade were equivocal.

### 5. *Lycium* – in Australia

There are three naturalised species of *Lycium* in Australia (*L. ferocissimum*, *L. barbarum*, *L. afrum*) and one endemic species (*L. australe*) (Figure 6) (Haegi 1976, Purdie et al. 1982).



Figure 6. *Lycium* species. A & B *Lycium barbarum*, C *Lycium australe*, D *Lycium afrum*, E *Lycium europaeum*

*Lycium barbarum* (Chinese Boxthorn, Goji Berry) (syn. *L. chinense*) is native to central China and was introduced to Australia as a garden plant, possibly from Europe, and has established weakly in coastal and near-coastal areas of south-east Queensland, NSW, Victoria, South Australia and Tasmania. The species can be difficult to distinguish from *L. ferocissimum* at the flowering stage. *L. barbarum* is an important herbal and medicinal plant in Asian culture and has recently received considerable attention for its potential therapeutic properties. It has some potential a future crop in Australia for medicinal and culinary

purposes. It is unlikely that other *Lycium* utilised to a minor degree elsewhere have economic potential in Australia e.g. *L. pallidum*, *L. europeum*, and *L. andersonii*.

*Lycium afrum* (Kaffir Boxthorn) is native to South Africa and although considered naturalised in southern Victoria, records are uncommon. A single record of *L. afrum* occurs near Hobart, Tasmania collected on 18/11/1912, but the species is not considered naturalised.

*Lycium europaeum* is not naturalised in Australia, although it has been listed as a host for several arthropods in northern NSW. It is uncertain if this plant was grown intentionally in horticulture or was misidentified and should have been listed as *L. ferocissimum*.

*Lycium australe* (Australian Boxthorn) (Figure 6) is endemic to mainland Australia and occurs in arid and semi-arid areas of NSW, Victoria, South Australia and Western Australia (Haegi 1979). Although *L. australe* and *L. ferocissimum* both align within an Old World clade (Levin & Miller 2005, Levin et al. 2007, Fukuda et al. 2001) (Figure 4), there are several linkages between the two species indicating some degree of phylogenetic differentiation.

## 6. *Lycium ferocissimum*

### 6.1. Habitat

*L. ferocissimum* is a common weed of agricultural and semi-arid pastoral areas and waste places, particularly around towns and cities. It is tolerant of many soil types, including poor, shallow rocky soils, and does well on lighter soils, particularly along dry creek beds (Muyt 2001, Parsons & Cuthbertson 1992). *Lycium ferocissimum* will tolerate salinised soil and grows at the edge of salt lakes and in clay pans. It is regarded as a halophyte (Webb et al. 1988). *Lycium ferocissimum* is most commonly found in *Eucalyptus* woodlands (1438 records, Atlas of Living Australia), *Eucalyptus* open forest (933 records), mallee woodlands and shrublands (397 records) and chenopod shrublands and forblands (286 records). It is recorded to a lesser extent in grasslands, saltwater lakes, *Callitris* woodlands, *Casuarina* woodlands, *Acacia* shrublands, forests and woodlands, shrublands, mangrove, grassland and heathland.

## 6.2. Distribution

*L. ferocissimum* is native to the southern coastal belt of South Africa where it is widespread and in the Western Cape, Northern Cape, Free State and Eastern Cape (Arnold & de Wet 1993, Welman 2003) (Figure 7). In its native range it is found on sandy soils, dry stony flats, and is regarded as unpalatable (Palgrave 2002). There are records from Morocco and Tunisia, (<http://www3.amherst.edu/~jsmiller/LycieaeWeb/Africa/Lferocissimum.html>), but these are doubtfully indigenous. It is a major weed in Australia and New Zealand (Parsons & Cuthbertson 1992; Roy et al. 1998). In New Zealand, it is largely restricted to coastal areas in North and South Island (Webb et al. 1988), whereas in Australia it is present in all states, but only widely distributed in New South Wales, Victoria and South Australia. It also occurs on Lord Howe Island and Norfolk Island. This species has not been distributed widely around the world. In the USA, the plant is recorded from Massachusetts, North Carolina and Florida, but details are lacking (Kriticos et al. 2010), while in California it is naturalised, but rare (DiTomaso & Healy 2007). It is listed as a noxious weed in North America (<http://plants.usda.gov/plants>). There are also introduced locality records for south west Spain and Cyprus (cited in Kriticos et al. 2010).

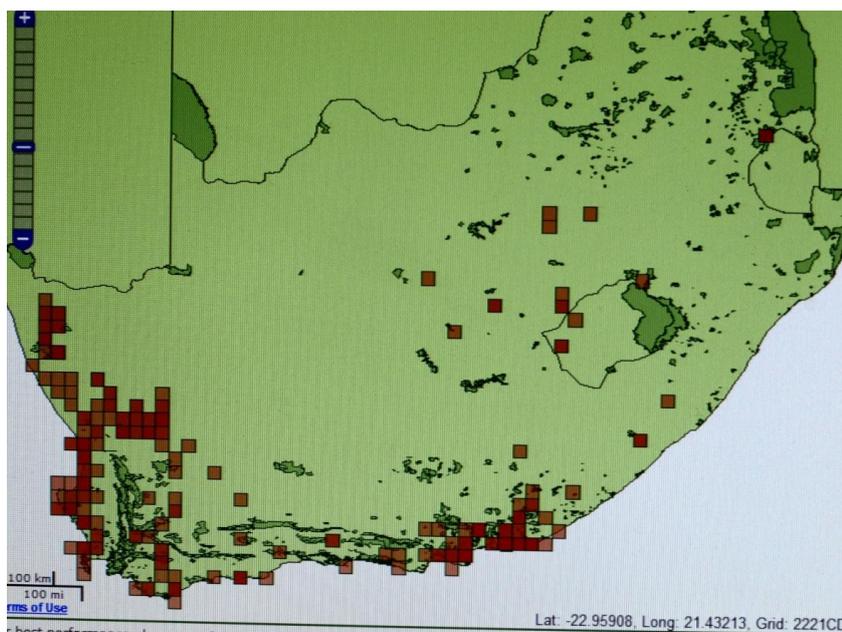


Figure 7. Distribution of *Lycium ferocissimum* in South Africa. Courtesy: SABIF (<http://sibis.sanbi.org>). Darker shading in the distribution squares indicates greater abundance.

### 6.3 Distribution within Australia

*L. ferocissimum* was introduced into Australia in late 19<sup>th</sup> century and utilised as a hedge plant in rural areas (Haegi 1979). It may have been utilised by necessity, along with other spiny shrubs, in the 1800's when barbed wire shortages were experienced due to war needs in overseas campaigns.

*Lycium ferocissimum* is naturalised in Australian states and territories, and is abundant in South Australia, Victoria and New South Wales. The islands of Bass Strait, Great Australian Bight and the southern Indian Ocean are particularly susceptible to invasion by *L. ferocissimum*. It also occurs on Lord Howe Island and Norfolk Island (Figure 8).

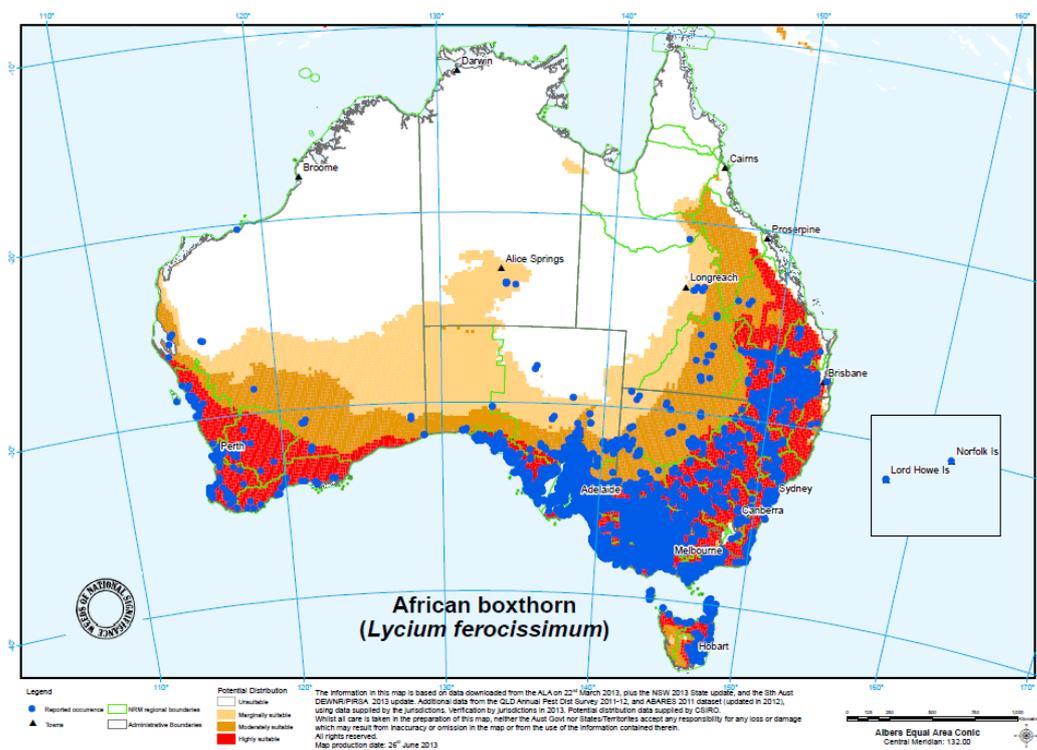


Figure 8. Current and potential Australian distribution of *Lycium ferocissimum*. Current distribution (blue). Potential distribution zones are high risk (red), moderate risk (dark orange), marginal risk (pale orange) and unsuitable (white). Figure courtesy Christopher Auricht.

*Lycium ferocissimum* is abundant in semi-arid temperate areas, where it is mostly found close to permanent or seasonal water sources (Haegi 1979). It is a common weed of agriculture in semi-arid pastoral areas and rangelands in South Australia, western New South Wales and Victoria, and waste places around cities and towns (Haegi 1979). *Lycium ferocissimum* is problematic in natural ecosystems and contributes to loss of biodiversity where it crowds out

vegetation and prevents natural regeneration (Muyt 2001). Further range expansion can be anticipated, particularly in Western Australia (Figure 8).

#### **6.4 Breeding systems, seed production and dispersal**

*L. ferocissimum* is diploid, hermaphroditic and strongly self-incompatible (Minne et al. 1994, Miller et al. 2008). In controlled experiments, 75% of out-crossed flowers produced fruits compared to 8 % of self pollinated flowers (Miller et al. 2008). Self-incompatibility is ancestral in the genus and occurs in southern African *Lycium*, e.g. *L. cinereum* and *L. hirsutum* (DeWaal et al. 2008). Phylogenetic analysis suggests self-incompatibility was derived from a single dispersal event of *Lycium* from the New to the Old World (DeWaal et al. 2008).

*Lycium ferocissimum* flowers from July to March in New Zealand (Roy et al. 1998) and Australia and similarly within its native range in South Africa. However, *L. ferocissimum* is capable of flowering and fruiting at any month providing sufficient moisture is available (CABI 2013). Plants can flower from 2 years of age. Each berry contains up to 70 yellow or light-brown, oval, flattened seeds approximately 2.5 x 1.5 mm in size. There is a positive linear relationship between fruit size and seed number (Erkelenz 1993).

In Australia, the fruit of *L. ferocissimum* is eaten by a range of native and exotic birds, and viable seeds may be excreted. Ornithochory (dispersal by birds) is an important mechanism of dispersal of *L. ferocissimum* and dense infestations often develop along fence lines or roosting trees, where seeds are defecated. The following native birds are reported consuming fruit of *L. ferocissimum*: silvereyes (*Zosterops lateralis*), currawong (*Strepera* sp.), silver gull (*Larus novaehollandiae*), little raven (*Corvus mellori*), Pacific gull (*Larus pacificus*), purple-crowned lorikeet (*Glossopsitta pusilla*), little wattlebird (*Anthochaera lunulata*), red wattlebird (*Anthochaera carunculata*), singing honey eater (*Lichenostomus virescens*), yellow-faced honey eater (*Lichenostomus chrysops*), spiny-cheeked honey eater (*Acanthagenys rufogularis*) and mistletoe bird (*Dicaeum hirundinaceum*). Similarly, exotic birds also consume and spread seeds namely: blackbird (*Turdus merula*), starlings (*Sturnus vulgaris*) and house sparrow (*Passer domesticus*) (Pizzey & Weatherly 1988, Lawley et al. 2005, Towns 2002, Lindsay & Meathrel 2008, Wallace 1986). Seeds may be

consumed by birds without loss of viability (Stanley & Lill 2002).

Australian lizards are also implicated in the dispersal of *L. ferocissimum* as fruits are consumed by the shingleback (*Tiliqua rugosa*) (Dubas & Bull 1991) and Cunningham skink (*Egernia cunninghami*) (Carr 1993). Similarly, lizards in the Canary Islands and Argentina consume fruits of native *Lycium* (Azocar & Acosta 2011, Nogales et al. 1998, Valido & Nogales 1994).

Double endochory is also reported where shrikes and kestrels regurgitate pellets that contains the remains of lizards which have fed on the fruits of *Lycium intricatum*. External seed damage by ingestion of lizards and shrikes was negligible, but seed coats were thinner after ingestion by kestrels (Nogales et al. 2007). *L. intricatum* seeds from shrike pellets showed significantly higher germination rates than those from uneaten fruits and lizard droppings (Nogales et al. 1998).

In Australia, the red fox eat and disperse fruit of *L. ferocissimum* (Lunt et al. 1998), while in New Zealand, the Pacific rat (*Rattus exulans*), is reported to consume fruit and seeds (Campbell et al. 1984).

### 6.5 Genetic variability

The base chromosome number for *Lycium* is  $n=12$  ( $2n=24$ ) (Cabrera 1981), although hybridization probably occurs as triploids and hexaploids have been identified (CABI 2013). The chromosome number for *L. ferocissimum* is  $2n=24$  (Laura 2010). The American species *L. californicum* var. *californicum* showed  $n=24$  and *L. fremontii* var. *fremontii* showed  $n= 48$  and one count of  $n= 60$  (Cabrera 1981).

There are no data available on the genetic variability of *L. ferocissimum* in Australia and South Africa. As the distribution in South Africa indicates a level of segregation into three population regions (Western Cape, Eastern cape, Orange Free State), it is possible some divergence has occurred between these populations. This remains to be tested, but would have relevance to a biological control program, particularly where agents with high levels of host specificity are under consideration e.g. rust fungi.

The source locations of Australian populations of *L. ferocissimum* are unknown.

Identification of South African populations that have a close genetic match to those in Australia would benefit the selection of potential biological control agents should a program be initiated.

## 6.6 Importance of the plant

### 6.6.1 Detrimental Aspects - Agriculture

Large clumps of *L. ferocissimum* eliminate pasture and impede movement of stock (Parsons & Cuthbertson 1992). The species is suspected as toxic, but there are no data based on feeding tests. Leaves may be toxic to chickens (Parsons & Cuthbertson 1992) and its leaves may contain chemicals making them unpalatable to livestock (CABI 2013). Tropane alkaloids are the suspected toxin and can affect all animal species, although the level of risk is believed to be low (Mckenzie 2012). Although the fruits are reported as edible, it may be responsible for producing narcotic symptoms in humans (Everist 1974).

*Lycium ferocissimum* is host to a range of pests and pathogens of concern to Australian agriculture, although some are currently not known to be present in Australia. The potato/tomato psyllid (*Bactericera cockerelli* (Sulc)) is a major pest of solanaceous crops and causes yield loss by direct feeding on crop plants and by transmitting the bacterial pathogen "*Candidatus Liberibacter psyllaurosus*". In western North America, the psyllid caused losses in tomato production from 50-80% as a new psyllid biotype adapted to local conditions (Liu et al. 2012). Species of *Lycium* are hosts to *B. cockerelli* including: *L. ferocissimum*, *L. andersonii*, *L. barbarum*, *L. exsertum*, *L. fremontii*, *L. pallidum*, *L. parishii*, *L. quadrifidum*, *L. macrodon*, *L. torreyi* (Fowler 2013, Butler 2011, Biosecurity Australia 2009). The tomato psyllid and its bacterial pathogen are not present in Australia, but they occur in New Zealand. Establishment of infected tomato psyllids in Australia would have detrimental economic impacts and *L. ferocissimum* is expected to act as a host, which would facilitate its dispersal.

Similarly, the green peach aphid *Myzus persicae* uses *Prunus* and *Lycium* as primary hosts and has over 400 secondary hosts. The aphid transmits 133 viruses many of which adversely affect plants of economic importance (Maramorosch & Harris 1991). The green peach aphid is present in Australia

and has been recorded from an unspecified *Lycium* in Tasmania (APPD 2013). It is likely *L. ferocissimum* may serve as a food source for the aphid, together with the pathogens the aphid may carry. *Lycium ferocissimum* is recorded as susceptible to Alfalfa Mosaic Virus (AMV), Tomato Spotted Wilt Virus, and the Tobacco Mosaic Virus (TMV), (Horváth 1991). The native *L. australe* is susceptible to Potato Virus X, Potato Virus Y, Tomato Ring Spot Virus, Tomato Mosaic Virus, Broad Bean Wilt Virus, Cucumber Mosaic Virus, Melandrum Yellow Fleck Virus, Tomato Rattle Virus, Tobacco Necrosis Virus, and Turnip Mosaic Virus (Horváth 1991).

#### 6.6.2 Detrimental Aspects – Biodiversity

Martin et al. (2006) lists *L. ferocissimum* as a threat to two Australian biodiversity hot spots that are utilised as rangelands: the Brigalow (North and South) in Queensland, and the Carnarvon Basin, Western Australia. The threat is associated with biomass accumulation, replacement of native vegetation, and reduced access, particularly to water and waterways. In contrast, Erkelenz (1993) found no clear evidence of *L. ferocissimum* displacing native vegetation at Cape Bauer (South Australia) and invasion is probably linked to prior disturbance events created by grazing pressures.

*Lycium ferocissimum* is perceived as priority threat to coastal habitats in Victoria, South Australia and Tasmania (Cousens et al. 2013). A range of species and vegetation communities are listed as adversely affected by *L. ferocissimum* (Appendix 3). Most of these are located in south-eastern Australia and an invasion of *L. ferocissimum* is one of many weeds causing conservation problems. Invasions of *L. ferocissimum* on oceanic islands appear to have serious implications for biodiversity management. *Lycium ferocissimum* arrived on Carnac Island (Western Australia) in 1992 and has potential to dominate vegetation there (Abbot et al. 2000). The species is present on 49 islands in South Australia (Robinson 1996) and on East Waldegrave Island (South Australia) forms a tall open shrubland on areas disturbed by sheep grazing prior to incorporation into a conservation reserve. On coastal islands off South Australia and Western Australia, *L. ferocissimum* displaces the native chenopod shrub *Nitraria billardieri*, which is used by fur seals to shelter pups. *Lycium*

*ferocissimum* does not provide a nursery habitat for seals, leaving pups at risk from predation (Kikkawa & Moritz 1994). In Bass Strait, *L. ferocissimum* has potential to spread and destroy breeding habitat of burrowing seabirds (Brothers 2001). *Lycium ferocissimum* was recorded on 53 of the 100 islands in the Outer Furneaux group of islands (Harris et al. 2001). On the Althorpe Islands (South Australia), the fine dense root system of *L. ferocissimum* may prevent burrowing of the short-tailed shearwater. After the removal *L. ferocissimum*, burrow density increased (Lawley et al. 2005). On Monunau Island (New Zealand), *L. ferocissimum* increased after the removal of rabbits causing detrimental impacts on fairy prions (*Pachyptila turtur*) and white-faced storm petrels (*Pelagodroma marina*), which were ensnared on the shrub's long spines, and impeded access to nesting areas (Priddel et al. 2000, Beach et al. 1997, Taylor 1968).

Several Ramsar wetland management plans and Ecological Character Descriptions identify *L. ferocissimum* as one of the main weed threats. These Ramsar sites include Port Phillip and Western Port (Vic), Western District lakes (Vic), Cheetham Wetlands (Vic), the Gwydir Wetlands (NSW), the Riverland (SA), Lake Warden System (WA), Fivebough and Tuckerbil Swamps (NSW), Towra Point Nature Reserve (NSW), Pittwater-Orielton (Tas), Moulting Lagoon (Tas) and Logan Lagoon (Tas).

Thickets of *L. ferocissimum* provide habitat for rabbits and foxes (White et al. 2006).

### 6.6.3 Beneficial Aspects

There are numerous beneficial uses of *Lycium*, but few specifically relate to *L. ferocissimum*. The Chinese species, *L. barbarum* (Goji Berry, Wolfberry, Chinese *Lycium*) has received considerable attention in the last decade as a source of therapeutic extracts with a wide range of potential uses e.g. Farnsworth et al. (2008).

In its native range, *L. ferocissimum* and other thorny shrubs play an important role in providing refuge sites for palatable species that might otherwise be lost from overgrazed rangelands (Todd 1999). This may also apply in limited situations in Australia, as *L. ferocissimum* may provide protection to the vulnerable South Australian endemic *Prostanthera calycina* (West Coast Mint bush) from overgrazing (Pobke 2007). *Lycium ferocissimum* can also provide

habitat to native animals including the endangered eastern-barred bandicoot (*Perameles gunnii*) that utilises patches of grassland bordered by native vegetation or spiny shrubs, including *L. ferocissimum* providing cover from predators (Heinsohn 1966). The fruits and seeds of *L. ferocissimum* are consumed by the southern brown bandicoot (Quin 1985). Roger et al. (2007) found a positive association between wombat burrows and *L. ferocissimum* (and blackberry), but not native shrubs and suggested there may be structural differences between the two groups and weeds provide better support and protection from predators, or cope better with wombat disturbance.

Australian apiarists may benefit from *L. ferocissimum* as honey bees work *L. ferocissimum* for nectar and pollen for brood rearing, and may be beneficial to beekeepers that move hives during drought (Clemson 1985). Although *L. ferocissimum* is suspected of being toxic to chickens (Parsons & Cuthbertson 1992), the shrub is advocated in permacultural systems for protection of chickens from hawks, dogs and cats (Mollison & Slay 1994).

The native *L. australe* has edible fruits that were traditionally eaten by aborigines in Victoria and South Australia (Hawkes 1979). *Lycium australe* is not cultivated or utilised in agriculture or horticulture, but can become over abundant on rangelands (Cunningham et al. 1981).

Exotic *Lycium* are not utilised as ornamentals in Australia and are unlikely to be promoted as such with several members regarded as invasive.

## 7. Control options

The control options for *L. ferocissimum* are described in detail in the African Boxthorn Best Practise Management Manual (Noble & Rose 2013) and the following section is based on that report.

*Lycium ferocissimum* infestations almost always require a series of treatment combinations over many years due to its capacity to regenerate from root stock, stems and seed.

### 7.1 Mechanical control

Suitable mechanical techniques for managing *L. ferocissimum* include:

- winching

- plucking
- dozing, stick raking and blade ploughing
- cultivation
- machine-based cut stump

## **7.2 Winching**

Pulling or winching can be used to remove large plants in difficult-to-access or fragile areas. Cutting and pasting remaining roots with herbicide will minimise regrowth.

## **7.3 Pulling or plucking**

Plucking is a useful technique for treating light to moderate infestations, and minimises impacts on surrounding vegetation. The technique involves mechanical equipment to physically remove individual plants and as much root mass as possible.

## **7.4 Dozing, stick raking and blade ploughing**

These methods are most suitable for moderate to heavy *L. ferocissimum* infestations where damaging non-target vegetation and the landscape is not a concern

## **7.5 Cultivation**

Suitable in areas designated for development of pasture or crops The technique can also be used for the dual purpose of destroying rabbit burrows and habitat. Regrowth from root fragments and seedlings may occur.

Establishing vigorous pasture or crop growth will help to prevent re-establishment of *L. ferocissimum*, by providing competition.

## **7.6 Mechanical cut stump**

This method involves cutting the plant near its base then immediately applying herbicide. e.g. Ecoblade®.

## **8. Chemical control**

Chemical control should be undertaken when the plant is actively growing and

not under stress.

Suitable chemical control techniques for managing *L. ferocissimum* include:

- foliar spraying
- cut-stump application
- stem injection or frilling
- basal bark application
- soil/root zone application

A range of herbicides are registered for use on *L. ferocissimum* in Australia.

### **8.1 Foliar spraying**

Mature *L. ferocissimum* plants have deep root systems which seem resilient beyond primary control through foliar spraying, often requiring retreatment. Plants should be sprayed when they are actively growing and have sufficient foliage to absorb the herbicide. Herbicides used for foliar application on *L. ferocissimum* include: triclopyr with picloram; a mixture of triclopyr-picloram and aminopyralid; glyphosate; picloram and 2,4-D amine. Foliage shed may occur after herbicide applications.

### **8.2 Cut stump application**

This method involves cutting the stem or stump approximately 100 mm above ground level, then applying herbicide to the cut surface. The cut-stump method is useful for isolated plants, smaller infestations near waterways, and plants close to sensitive native vegetation or infrastructure.

### **8.3 Stem injection/frilling**

Stem injection involved drilling holes into the trunk at an angle. Frilling involves using an axe or similar tool to expose sections of inner bark. Herbicide is then applied immediately onto the cambium. This method is suited to large isolated plants with a trunk diameter over 50 mm. Herbicides used for basal bark application include triclopyr with picloram; and triclopyr based herbicides.

#### **8.4 Basal bark application**

This technique is generally effective on bushes with a trunk diameter of up to 50 mm. Herbicide is applied to the basal bark and root system. It is often mixed with diesel and applied with a knapsack sprayer. This method is best suited to isolated bushes where boxthorn trunks/stems are easily accessed, and is useful for boxthorn control where retaining dead standing boxthorn as temporary habitat for native fauna.

#### **8.5 Soil–root zone application**

Herbicide is applied evenly to the soil near the drip line of the bush, when the soil is wet or rainfall is predicted. Soil-applied herbicides move through the root zone after rain and are absorbed into the roots. Residual herbicides can remain active in the soil for a long time, can travel downhill on steep or sloping ground and can leach into the water table. This method is best suited for use in agricultural areas away from non-target trees and shrubs, native vegetation or waterways.

### **9. Other control options**

Hand pulling can be an option for very small plants. It is generally easier to do after rain, when the soil is wet. The entire tap root must be pulled out, or the plant will regrow.

Fire can be useful to clear the woody branches and assist with access, but will also encourage *L. ferocissimum* regrowth from rootstock.

Grazing is generally not a useful control option. *Lycium ferocissimum* plants (fruit, leaves, stem and roots) are considered poisonous to livestock.

### **10. Potential for biological control**

There has been no previous evaluation of *L. ferocissimum* as a candidate for biological control and all the information gathered for this review has been collected from independent and varied sources. Despite being problematic in

only two countries (Australia and New Zealand), there was a modest source of information available on the entomology and pathology of *L. ferocissimum* and its congeners. This can be attributed to several factors including the importance of related species for therapeutic functions, particularly *L. barbarum* and *L. chinense*; inclusion in the Solanaceae, an economically important family; native in a region with strong entomological and pathology skills (South Africa); and a species of some agricultural relevance in its country of origin.

### 10.1 Biota associated with related non-African species

Entomological records were found for 19 species of non-southern African *Lycium*, with three or more species recorded for *L. chinense* (9), *L. barbarum* (11), *L. europaeum* (5), and *L. ruthenicum* (4) (Appendix 4). There are a total of 44 arthropods recorded from non-southern African *Lycium*, with highest diversity from the Eriophyiidae (8 species), Lepidoptera, particularly Coleophoridae, (10 species), Coleoptera (8 species) and Hemiptera (10 species). Many of the arthropods appear to be monophagous, although records often lack biological information that allows accurate assessments of host range.

In this group of *Lycium*, 17 different pathogens have been recorded from seven species of *Lycium*. Chinese *Lycium* (*L. barbarum*) had the highest diversity of pathogens, with 11 species recorded from this host. Rusts (*Puccinia* spp.) appear to be the more diverse pathogens associated with *Lycium* (Appendix 4). Twenty-four viruses are known from non-African *Lycium* (Horvarth 1991).

### 10.2. Biota in South Africa

In southern Africa, there are 23 native species of *Lycium* (<http://posa.sanbi.org/>), eight of these (excluding *L. ferocissimum*) host phytophagous arthropods and two species are known to host pathogens. A total of 15 phytophagous arthropods are recorded from southern African *Lycium*, excluding *L. ferocissimum*. The Eriophyiidae (5 species) is the most diverse group, followed by Lepidoptera (3), Hemiptera (4), Coleoptera (2) and Diptera (1) (Figure 9).

Large, woody shrubs generally support a rich assemblage of phytophagous arthropods, but these are generally only realised when the plant is targeted for entomological surveys. The South African shrub *Chrysanthemoides monilifera* has 113 phytophagous arthropods, three fungi and a mycoplasma and 46 of these have potential as biological control agents (Scott and Adair 1990). Similarly, 28 phytophagous species from six orders are recorded from the South African shrub *Polygala myrtifolia*, (Adair et al. 2011), 400 from *Delairea odorata* Lem. (Grobbelaar et al. 2003), 14 from *Senecio madagascariensis* Poir. (Marohasy 1989), 31 from *Solanum linnaeanum* Hepper & P-M.L.Jaeger, 49 from *S. panduriforme* Drège ex Dunal, and 33 from *S. incanum* L. (Olckers & Hulley 1989, Olckers et al. 1995).



Figure 9. Phytophagous arthropods from *Lycium*. A *Aceria kuko* on *Lycium chinense*,. B *Thrips imaginis* recorded from *L. ferocissimum*, C *Armillaria novae-zealandiae* recorded from *L. ferocissimum* in New Zealand,, D *Udea ferrugalis* recorded from *Lycium oxycarpum*, E *Philotherma rosa* from *L. oxycarpum*, F *Bactrocera tryoni* from *L. ferocissimum*, G *Coccus hesperidum* from *L. ferocissimum*, H *Carpophilus hemipterus* from *L. ?europaeum*, I *Sceliodes cordalis* recorded from *L. ferocissimum*.

Comparatively, the faunal and pathogen records for *L. ferocissimum* are low with only 5 arthropods and one pathogen recorded in its native range. However, four of these appear to be monophagous as they are only recorded from *L. ferocissimum*: the tortoise beetles *Cassida lycii*, *C. distinguenda*, *C. melanophthalma*, and the pathogen *Puccinia rapipes*. Several common and polyphagous arthropods are also recorded from *L. ferocissimum* in South Africa (Appendix 4). Undoubtedly, targeted surveys would substantially increase the census of phytophagous organisms from *L. ferocissimum* across all major orders, particularly the Lepidoptera, Coleoptera, Hemiptera and Diptera as these orders are represented in many other *Lycium* from around the world (Appendix 4). Pathogens may also be under-reported for *L. ferocissimum* in South Africa. Six species of *Puccinia* have been described from *Lycium* in Africa, near and middle east, and southern Europe (Berndt & Uhlmann 2006), including *P. rapipes*, which was described from *L. ferocissimum* on the Cape Peninsula at Simonstown, a location with excellent climatic match to many *L. ferocissimum* infestations in Australia. The potential of *P. rapipes* for biocontrol in Australia is considerable.

The hemipteran genera *Bactericera*, *Diaphorina*, *Russeliana* and *Trioza* are well represented on *Lycium* worldwide with a total of nine species recorded (Appendix 4). *B. cockerelli* is a polyphagous pest and a biosecurity concern to Australia as it feeds on Solanaceous crops. Others appear to be more host-specific and may have potential for biocontrol of *L. ferocissimum*, providing they are convincingly not associated with plant diseases.

### **10.3. Biota in Australia**

Surprisingly, there are 12 phytophagous arthropod and pathogen reported from *L. ferocissimum* in Australia, nearly all from the Australian Plant Pest Database (<http://www.planthealthaustralia.com.au/resources/australian-plant-pest-database/>).

This may be an under-estimation, if the records for *L. europaeum* in NSW where the result of misidentification of the host. Nearly all records are of polyphagous pests and none appear to be specific to *L. ferocissimum*.

Preliminary targeted searching for arthropods and pathogens on *L. ferocissimum* in Australia demonstrated further records (Appendix 5). Nineteen sites were

sampled and at most sites, the number and diversity and abundance of phytophagous organisms and pathogens were low. Many were single occurrences and possibly present on *L. ferocissimum* as casual visitors, rather than phytophagous biota. Many specimens could not be identified beyond family or order. The herbivory level on leaves, stems and fruits of *L. ferocissimum* was generally very low (<1%). Fruits were often damaged by birds and either wholly or partially eaten. Thrips were present at many sites, and were a common phytophage on *L. ferocissimum*. Tephritidae were probably under-sampled, due to the sampling season, but no visual evidence was apparent on fruits seen. There appears to be a number of fungal pathogens on the foliage and fruits of *L. ferocissimum* (Figure 10), but moist incubation techniques failed to generate fruiting material needed for accurate determinations. *Lycium* leaves degrade quickly after picking. Further sampling in Spring and Summer is likely to yield a greater diversity and abundance of phytophagous biota and more success in rearing pathogens to reproductive stages.



Figure 10. Organisms from Australian *Lycium ferocissimum*. A *Acizzia* sp. damage (LHS). B Close up of *Acizzia* damage. C pathogen with white lesions, D pathogen with black lesions.

In this study, a new species of psyllid (*Acizzia* sp.) was recorded from *L. ferocissimum* in Australia. This is the first record of a psyllid feeding on Australian *Lycium* and the first record of *Acizzia* from *Lycium*. Although three *Acizzia* species have recently been recorded from other Solanaceae in Australia (Taylor and Kent 2013, Kent and Taylor 2010), this species is clearly different and undescribed (Taylor pers. comm. 2013). *Acizzia* are predominantly associated with *Acacia* (Taylor and Kent 2013). The insect was widespread in Victoria and densities on *L. ferocissimum* were often high where they caused considerable damage by stunting growth, chlorosis, distortion of foliage, and contraction of internodes (Figure 10). Stem death was also observed. The psyllid may also be widespread in other states and territories, but further surveys are required to determine its full distribution. It is not known at this stage whether Australian populations of the insect are vectors of the pathogen *Candidatus*. The mealy bug *Pseudococcus* sp. commonly shelter and feed amongst the compacted growth caused by *Acizzia*, further contributing to stem weakening.

#### **10.4. Biocontrol potential**

*Lycium ferocissimum* has been suggested as a target for biological control in Australia (Julien 2006), but the concept has not yet achieved the necessary traction. In an evaluation of potential biological control targets of Australian weeds, Paynter et al. (2009) ranked *L. ferocissimum* as 31 out of the 75 weeds assessed, a score similar to that allocated to *Acacia nilotica* spp. *indica* (Prickly Acacia) and *Cytisus scoparius* (English Broom), which are targets for biological control in Australia.

More detailed surveys in the country of origin are required to evaluate the full potential for biocontrol of *L. ferocissimum*. However, preliminary evaluation clearly indicates that potential agents are present and warrant further evaluation. The rust fungus *P. rapipes* (Figure 11) is a strong potential biocontrol candidate as it is likely to be specific and damaging to *L. ferocissimum*. Similarly, several tortoise beetles recorded from *L. ferocissimum* could be considered. *Cassida* have been used in other biocontrol systems with some success e.g. *Cassida rubiginosa* on Californian thistle in New Zealand (Figure 11) (Cripps 2013).

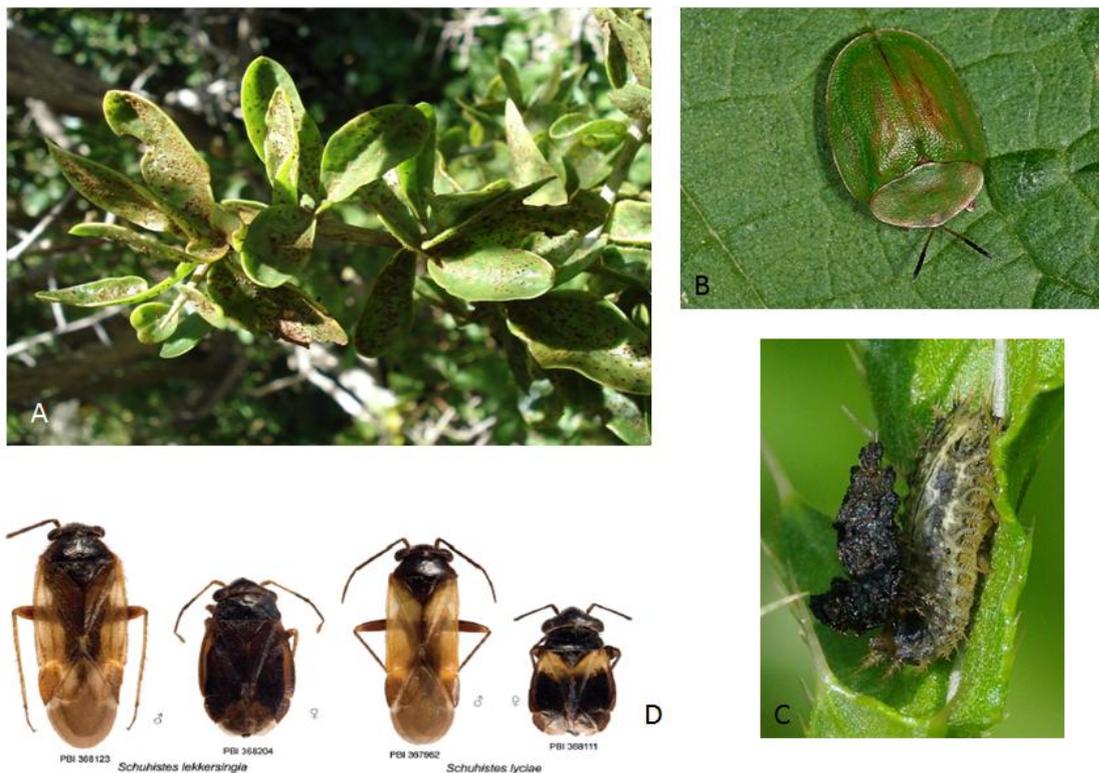


Figure 11. Potential biological control agents for *Lycium ferocissimum* in Australia. A *Puccinia rapipes* (photo Alan Wood), B-C *Cassida* spp. D two *Schuhistes* species (photo after Menard 2010).

### 10.5. Risks associated with biocontrol

The phylogenetic distance of the Lychieae from other members of the Solanaceae, particularly plants of economic and ecological importance in Australia (Stevens 2001), provides an opportunity to develop a safe and host-specific biocontrol program.

*Lycium australe* is the only native member of the genus, but has a close phylogenetic relationship with the Old World clade of *Lycium*, including *L. ferocissimum*. Clearly, the selection program for potential biocontrol agents will need to carefully evaluate potential impacts on this species. Agents with high levels of specificity are likely to be the only ones suitable for biocontrol in Australia.

Sap-feeding arthropods will require careful evaluation if being considered as biological control agents. *Lycium ferocissimum* hosts viruses and pathogens of

economic importance and rigorous screening will be required for this guild, if they are to be considered as biocontrol agents.

Although *L. barbarum* is not commercially utilised or cultivated in Australia, it is becoming increasingly important as a potential source of therapeutic products, and future industries may develop around the use of this plant. A biocontrol program for *L. ferocissimum* needs to evaluate the impact of prospective agents on this species and avoid the selection of those that are particularly damaging. Reconsideration of this approach may be required if *L. barbarum* expands its range in Australia, or formal weed risk assessments determine it to be with high potential risk to the economy or environment.

## 11. Conclusion

*Lycium ferocissimum* is a suitable target for classical biological control in Australia. Its relative taxonomic isolation within the Solanaceae and the presence of only one native congener, reduces the potential for non-target damage. Literature records indicate host specific organisms are likely to occur on *L. ferocissimum* in its native habitat, but more detail surveys are required to establish a full census.

## 12. Stakeholders

Stakeholders considered relevant for consultation in the development of *Lycium* as a target for biological control are listed (Appendix 6).

## 13. Acknowledgements

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Appendix 1. List of *Lycium* species and their origin.

(source: <http://www.ipni.org/index.html>, <http://en.wikipedia.org/wiki/Lycium>, <http://posa.sanbi.org/>, Chiang-Cabrera 1981, Levin & Miller 2005, Levin et al. 2011)

Species	Common Name	Origin
<i>Lycium acutifolium</i> E.Mey ex Dunal.		South Africa
<i>Lycium afrum</i> L.		South Africa
<i>Lycium americanum</i> Jacq.		Argentina
Syn <i>L. salsum</i> Bartram		
<i>Lycium amoenum</i> Dammer		South Africa
<i>Lycium ameghinoi</i> Speg.		Argentina
<i>Lycium andersonii</i> Gray	Anderson Boxthorn, Anderson Thornbush, Anderson Wolfberry, Anderson Desert Thorn, Desert Tomato, Tomatillo	USA
<i>Lycium arenicola</i> Miers		South Africa
<i>Lycium arochae</i> Chiang		Mexico
<i>Lycium athium</i> Bernardello		Argentina
<i>Lycium australe</i> F.Muell.		Australia
<i>Lycium barbarum</i> L.	Duke of Argyll's Teaplant, Ningxia Wolfberry, Wolfberry	China
<i>Lycium boerhaviifolium</i> L		Argentina
<i>Lycium bosciifolium</i> Schinz		South Africa
<i>Lycium berlandieri</i> Dunal	Berlandier's Wolfberry	USA
<i>Lycium brevipes</i> Benth.		Mexico
<i>Lycium bridgesii</i> (Miers) Levin, Miller & Bernardello		Chile
<i>Lycium californicum</i> Nutt. ex Gray	California Boxthorn, California Desert-thorn	USA
<i>Lycium carolinianum</i> Walter	Carolina Desert-thorn, Christmas berry	USA
<i>Lycium cestroides</i> Schlttdl.		Argentina
<i>Lycium chilense</i> Bertero		Argentina
<i>Lycium chinense</i> Mill.	Chinese Teaplant, Wolfberry	China (syn <i>L. barbarum</i> by some)
<i>Lycium ciliatum</i> Schlecht.		Argentina
<i>Lycium cinereum</i> Thunb.		South Africa
<i>Lycium cooperi</i> A. Gray		USA
<i>Lycium cuneatum</i> Dammer		Argentina
<i>Lycium decumbens</i> Welw. ex Hiern		South Africa, Madagascar
<i>Lycium densifolium</i> Wiggins		Mexico
<i>Lycium depressum</i> Stocks		Asia (temperate)
<i>Lycium eenii</i> S.Moore		Namibia
<i>Lycium elongatum</i> Miers		Argentina
<i>Lycium europaeum</i> L.	European Wolfberry Wolfberry	Europe
<i>Lycium exsertum</i> A.Gray		USA
<i>Lycium ferocissimum</i> Miers	African Boxthorn	South Africa

<i>Lycium fremontii</i> A. Gray		Mexico
<i>Lycium fuscum</i> Miers		South America
<i>Lycium gariiepense</i> Venter		South Africa
<i>Lycium gillpesianum</i> Miers		Argentina
<i>Lycium grandicalyx</i> Joubert & Venter		Namibia
<i>Lycium hantamense</i> Venter		South Africa
<i>Lycium horridum</i> Thunb.		South Africa
<i>Lycium hirsutum</i> Dunal		South Africa
<i>Lycium infaustum</i> Miers		Argentina
<i>Lycium intricatum</i> Boiss		Canary Island
<i>Lycium leiospermum</i> I. M. Johnst.		Mexico
<i>Lycium longiflorum</i> Phil.		South America
<i>Lycium macrodon</i> A.Gray		USA
<i>Lycium mascarenense</i> A.M. Venter & A.J. Scott		South Africa, Mozambique, Madagascar
<i>Lycium megacarpum</i> Wiggins		Mexico
<i>Lycium minimum</i> C.L.Hitchc.		Ecuador
<i>Lycium minutifolium</i> Remy		Chile
<i>Lycium morongi</i> Britton		Bolivia
<i>Lycium nodosum</i> Miers		Argentina
<i>Lycium oxycarpum</i> Dunal		South Africa
<i>Lycium pallidum</i> Miers		USA
<i>Lycium parishii</i> A.Gray		USA
<i>Lycium pilifolium</i> C. W. Wright		South Africa
<i>Lycium puberulum</i> A.Gray		USA
<i>Lycium pumilum</i> Dammer		Namibia
<i>Lycium rachidocladum</i> Dunal		Chile
<i>Lycium ruthenicum</i> Murray		Eurasia
<i>Lycium sandwicense</i> A.Gray	'Ōhelo kai	Pacific
<i>Lycium schizocalyx</i> C.H.Wright		South Africa
<i>Lycium schockleyi</i> A. Gray		USA
<i>Lycium schaffneri</i> A. Gray		Mexico
<i>Lycium schweinfurthii</i> Dammer		Africa, Eurasia
<i>Lycium shawii</i> Roem. & Schult	Arabian Boxthorn	Africa
<i>Lycium sokotranum</i> Wagner & Vierh.		Yemen
<i>Lycium stenophyllum</i> Remy		Chile
<i>Lycium strandveldense</i> Venter		South Africa
<i>Lycium tenue</i> L.		South Africa (threatened)
<i>Lycium tenuispinosum</i> A. Gray		Argentina
<i>Lycium tetrandrum</i> Thunb.		South Africa
<i>Lycium texanum</i> Correll		USA
<i>Lycium torreyi</i> A. Gray		USA
<i>Lycium villosum</i> Schinz		South Africa
<i>Lycium vimineum</i> Miers		Argentina

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Appendix 2. List of Australian genera in the Solanaceae

Source: <http://www.anbg.gov.au/cgi-bin/apclist>

Genus	Total No. Species/subspecific taxa	No. exotic species
<i>Anthocercis</i>	18	0
<i>Anthotroche</i>	3	0
<i>Browallia</i>	1	1
<i>Brugmansia</i>	2	2
<i>Calibrachoa</i>	1	1
<i>Capsicum</i>	3	3
<i>Cestrum</i>	6	6
<i>Crenidium</i>	1	0
<i>Cyphanthera</i>	16	0
<i>Datura</i>	7	7
<i>Duboisia</i>	5	0
<i>Grammosolen</i>	3	0
<i>Hyoscyamus</i>	2	2
<i>Lycianthes</i>	2	1
<i>Lycium</i>	4	1
<i>Nicandra</i>	1	1
<i>Nicotiana</i>	32	2
<i>Nierembergia</i>	1	1
<i>Petunia.</i>	2	2
<i>Physalis</i>	14	14
<i>Salpichroa</i>	1	1
<i>Solandra</i>	1	1
<i>Solanum</i>	193	40
<i>Symonanthus</i>	2	0
<i>Withania</i>	1	1

Appendix 3. Species and vegetation communities adversely affected by *Lycium ferocissimum* )

Species or community	State	Status	Source	Note
<i>Lepidium aschersonii</i> (Spiny Peppergrass)	Victoria	Vulnerable	Carter (2010a)	<i>L. ferocissimum</i> has invaded habitat at Lake Beeac, Lake Corangamite
<i>Holosarcia flabelliformis</i> (Bead Glasswort)	Victoria	Endangered	Venn (2004)	<i>L. ferocissimum</i> a threat at Mitre Lake
<i>Santalum lanceolatum</i> (Northern Sandalwood)	Victoria	Endangered	Johnson (2003)	Problematic at Boundary Bend
<i>Ixodia achillaeoides</i> subsp. <i>arenicola</i> (Sand Ixodia)	Victoria, South Australia	Vulnerable	Carter (2010)	<i>L. ferocissimum</i> a threat to all sites
<i>Pterostylis despectans</i> (Lowly Greenhood)	Victoria, South Australia	Endangered	<a href="http://www.environment.gov.au/biodiversity/threatened/publications/recovery/p-despectans/index.html">http://www.environment.gov.au/biodiversity/threatened/publications/recovery/p-despectans/index.html</a>	<i>L. ferocissimum</i> a threat to some populations
<i>Pterostylis arenicola</i> (Sandhill Greenhood Orchid)	Victoria, South Australia	Vulnerable	<a href="http://www.environment.gov.au/sprat">http://www.environment.gov.au/sprat</a> .	<i>L. ferocissimum</i> a medium to high risk at 6 out of 9 sites
<i>Caladenia macroclavia</i> (Large-club Spider-orchid)	South Australia	Endangered	Quarmby (2010)	
<i>Acacia enterocarpa</i>	South Australia: Eyre Peninsula		Moritz & Bickerton (2011)	<i>L. ferocissimum</i> is a potential threat to Yorke Peninsula populations
<i>Acacia whibleyana</i> (Whibley Wattle)	South Australia	Endangered	Pobke (2007)	<i>L. ferocissimum</i> is a priority weed for control
<i>Microlepidium alatum</i>	South Australia	Vulnerable	<a href="http://www.environment.gov.au/sprat">http://www.environment.gov.au/sprat</a>	<i>L. ferocissimum</i> is a key threat and highly probable invader
<i>Dodonaea subglandulifera</i> (Peep Hill Hop Bush)	South Australia	Endangered	Moritz & Bickerton (2010)	<i>L. ferocissimum</i> threatens the population at Peep Hill
<i>Prostanthera eurybioides</i> (Monarto Mint bush)	South Australia	Endangered	Quarmby (2010)	Establishment of seedlings is threatened by <i>L. ferocissimum</i>
<i>Caladenia intuta</i> (Ghost Spider-orchid)	South Australia	Critically Endangered	Quarmby (2010)	

African Boxthorn – feasibility of biological control

Species or community	State	Status	Source	Note
<i>Carex tasmanica</i> (Curly Sedge)	Victoria, Tasmania	Vulnerable	Carter (2010)	<i>L. ferocissimum</i> one of a number of weed invaders threatening the species
<i>Lepidium monoplacoides</i> (Winged Pepper-cress)	New South Wales	Endangered	Mavromihalis (2010)	<i>L. ferocissimum</i> a threat at Lake Urana
<i>Neophema chrysogaster</i> (Orange-bellied Parrot)	Victoria, South Australia, Tasmania	Critically Endangered	Holdsworth (2006)	<i>L. ferocissimum</i> has capacity to swamp native food plants
<i>Dianella amoena</i> (Matted Flax-lily)	Victoria, Tasmania	Endangered	Carter (2010)	<i>L. ferocissimum</i> a threat at some sites
<i>Wurmbea tubulosa</i> Long-flowered Nancy	Western Australia	Endangered	<a href="http://www.environment.gov.au/sprat">http://www.environment.gov.au/sprat</a>	
Communities				
Coolibah – Black Box Woodland of the northern riverine plains in the Darling Riverine Plains and Brigalow Belt South bioregions	NSW	Endangered	NSW Scientific Committee (2004)	<i>L. ferocissimum</i> forms dense scrub thickets that may exclude native plant species
Porcupine Grass - Red Mallee - Gum Coolabah hummock grassland / low sparse woodland in the Broken Hill Complex Bioregion	NSW	Critically endangered	<a href="http://www.environment.nsw.gov.au/determinations/porcupinegrassFD.htm">http://www.environment.nsw.gov.au/determinations/porcupinegrassFD.htm</a>	<i>L. ferocissimum</i> occurs in nearby communities
Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Penepplain, Murray-Darling Depression, Riverina and NSW South western Slopes bioregions	NSW	Endangered	<a href="http://www.environment.nsw.gov.au/determinations/myallwoodland36a.htm">http://www.environment.nsw.gov.au/determinations/myallwoodland36a.htm</a>	Introduced shrubs, notably <i>Lycium ferocissimum</i> have invaded some areas.
Sandhill Pine Woodland in the Riverina, Murray-Darling Depression and NSW South Western Slopes bioregions	NSW	Endangered	<a href="http://www.environment.nsw.gov.au/determinations/sandhillpine36a.htm">http://www.environment.nsw.gov.au/determinations/sandhillpine36a.htm</a>	<i>L. ferocissimum</i> is a principal weed species
Mallee and Mallee-Broombush dominated woodland and shrubland, lacking <i>Triodia</i> , in the NSW South-western Slopes Bioregion	NSW	Critically endangered	Benson (2008)	The presence and cover of weeds in Bull Mallee - White Mallee variant, includes <i>L. ferocissimum</i> .

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Species or community	State	Status	Source	Note
Central Hunter Grey Box – Ironbark Woodland in the NSW North Coast and Sydney Basin Bioregions	NSW	Endangered	(Peake 2006).	The community has been invaded by <i>L. ferocissimum</i> .
Lowland Grassy Woodland in the South East Corner bioregion	NSW	Endangered	(Miles 2002).	Weed invasion also poses a major threat to Lowland Grassy Woodland. <i>L. ferocissimum</i> is a principal weed
Carbeen Open Forest community in the Darling Riverine Plains and Brigalow Belt South Bioregions	NSW	Endangered	<a href="http://www.environment.nsw.gov.au/determinations/carbeenopenforest36a.htm">http://www.environment.nsw.gov.au/determinations/carbeenopenforest36a.htm</a>	Remnants are threatened by weed invasion including <i>L. ferocissimum</i>
Dry Coastal Vegetation	TAS	Not critical	<a href="http://www.depiw.tas.gov.au">www.depiw.tas.gov.au</a>	One of several woody invaders.

Appendix 4. Phytophagous organisms associated with *Lycium*

Arthropods and pathogens recorded from <i>Lycium ferocissimum</i> (Australia)									
Host species	Order/Family	Genus/Species	Common Name	Distribution	Organ Damage <sup>1</sup>	Specificity <sup>2</sup>	Reference	Notes	Present in Australia
<i>L. ferocissimum</i>	Diptera: Tephritidae	<i>Bactrocera tryoni</i> Froggatt	QLD fruit fly	NSW	Fr	P	Fig. 9	ASCU / ASCT00008972 142 records	Y
<i>L. ferocissimum</i>	Hemiptera: Pseudococcidae	<i>Pseudococcus affinis</i> (Maskell)	Mealybug	South Australia	R, S, F, B	P	Williams 1985		Y
<i>L. ?ferocissimum</i>	Hemiptera: Coccidae	<i>Coccus hesperidum</i> Linnaeus	Soft brown scale	Tasmania		P	Fig. 9	TPPD / 69808 3 records	Y
<i>L. ferocissimum</i>	Lepidoptera: Pyralidae	<i>Sceliodes cordalis</i> Doubleday	Egg fruit caterpillar	NSW	S, Fr	O	Fig 9	ASCU / ASCT00033353 1 record	Y
<i>L. ferocissimum</i>	Thripidae	<i>Anaphothrips</i> sp.	Thrip	Queensland				QDPC / 0-125631 1 record	Y
<i>L. ferocissimum</i>	Thripidae	<i>Chaetanaphothrips</i> sp.	Thrip	Queensland				QDPC / 0-125630 1 record	Y
<i>L. ferocissimum</i>	Thripidae	<i>Thrips imaginis</i> Bagnall	Thrip	Queensland		P	Fig. 9	QDPC / 0-125632 1 record	Y
<i>L. ?ferocissimum</i>	Nematoda: Tylenchida: Hoplolaimidae	<i>Helicotylenchus pseudorobustus</i> (Steiner)	Spiral nematode	Victoria		P		APDD / VPRI-24170a 1 record	Y
<i>L. ferocissimum</i>	Botryosphaeriaceae	<i>Diplodia</i> sp.	Canker	South Australia	?S		Cook & Dubé 1989	APDD / ADW-5871a 2 records	Y
<i>L. ferocissimum</i>	Nectriaceae	<i>Nectria berkeleyi</i> Höhn		South Australia			Cook & Dubé 1989	APDD / ADW-7428a 1 record	Y
<i>L. ferocissimum</i>	Erysiphales	<i>Oidium</i> sp.	Powdery mildew	Tasmania			Sampson & Walker 1982 Amano 1986	APDD / DAR-22203a 1 record	Y

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<i>L. barbarum</i>									
<i>L. ferocissimum</i>	Pleosporales	<i>Phoma</i> sp.		South Australia			Cook & Dubé 1989	APDD / ADW-7422a 1 record	Y
<b>Arthropods and pathogens recorded from <i>Lycium ferocissimum</i> (Outside Australia)</b>									
<i>L. ferocissimum</i>	Coleoptera: Chrysomelidae	<i>Cassida lycii</i> Borowiec & Świętojańska	Tortoise beetle	South Africa	F	M	Borowiec & Swietojanska 2001		
<i>L. ferocissimum</i>	Coleoptera: Chrysomelidae	<i>Cassida distinguenda</i> Spaeth	Tortoise beetle	South Africa	F	M	Borowiec & Swietojanska 2001		
<i>L. ferocissimum</i>	Coleoptera: Chrysomelidae	<i>Cassida melanophthalma</i> Boheman	Tortoise beetle	South Africa	F	M	Borowiec & Swietojanska 2001		
<i>L. ferocissimum</i> :	Lepidoptera: Tortricidae	<i>Tortrix capensana</i> (Walker)	Leaf roller	South Africa	F	P	Kroon 1999		
<i>L. ferocissimum</i> :	Lepidoptera: Crambidae	<i>Udea ferrugalis</i> Hübner	Rusty dot pearl	South Africa	?F	P	Kroon 1999 Fig. 9		
<i>L. cf. ferocissimum</i>	Pucciniales	<i>Puccinia rapipes</i> R. Berndt & E. Uhlmann	Rust fungus	South Africa	F	M	Berndt & Uhlmann 2006 Fig. 10		
<i>L. ferocissimum</i>	Physalacriaceae	<i>Armillaria limonea</i>		New Zealand			Gadgil 2005		
<i>L. ferocissimum</i>	Physalacriaceae	<i>Armillaria novae-zealandiae</i>		New Zealand			Gadgil 2005		
<b>Arthropods and pathogens recorded from other <i>Lycium</i> spp. (Australia)</b>									
<i>L. europaeum</i>	Coleoptera: Chrysomelidae	<i>Arsipoda chrysis</i> Olivier	Flea beetle	NSW				ASCU / ASCT00104406 1 record	Y
<i>L. europaeum</i>	Coleoptera: Nitidulidae	<i>Carpophilus davidsoni</i> Dobson	Sap beetle	NSW	Fr	P	Walker, K. (2007) <a href="http://www.padil.gov.au">http://www.padil.gov.au</a> .	ASCU / ASCT00152572 6 records	Y
<i>L. europaeum</i>	Coleoptera:	<i>Henosepilachna vigintioctopunctata</i>	Twenty-six-spotted	NSW		P		ASCU /	Y

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	Coccinellidae	Fabricius	potato ladybird					ASCT00154634 1 record	
<i>L. europaeum</i>	Coleoptera: Curculionidae	<i>Lixus</i> sp.	Weevil	NSW				ASCU / ASCT00077344 1 record	Y
<i>L. europaeum</i>	Coleoptera: Nitidulidae	<i>Carpophilus hemipterus</i> Linnaeus	Dried fruit beetle	NSW	Fr	P	Fig. 9	ASCU / ASCT00151038 4 records	Y
<i>L. europaeum</i>	Hemiptera: Alydidae	<i>Leptocorisa acuta</i> Thunberg		NSW		P		ASCU / ASCT00132551 1 record	Y
<i>L. europaeum</i>	Hemiptera: Alydidae	<i>Melanacanthus scutellaris</i> Dallas	Small brown bean bug	NSW		P		ASCU / ASCT00132383 1 record	Y
<i>L. europaeum</i>	Hemiptera: Lygaeidae	<i>Nysius vinitor</i> Bergroth	Rutherglen bug	NSW		P	<a href="http://www.padil.gov.au">http://www.padil.gov.au</a>	ASCU / ASCT00145454 1 record	Y
<i>L. europaeum</i>	Hemiptera: Scutelleridae	<i>Scutiphora pedicellata</i> Kirby	Metallic jewel bug	NSW	F	P		ASCU / ASCT00135004 2 records	Y
<i>Lycium</i> sp.	Lepidoptera: Noctuidae	<i>Helicoverpa punctigera</i> Wallengren	Army worm	NSW		P		ASCU / 31- 012530 1 record	Y
<i>L. australe</i>	Uredinales	<i>Aecidium</i> sp.	Rust fungus	South Australia				APDD / ADW- 1555a 1 record	Y
<i>L. barbarum</i>	Erysiphales	<i>Arthrocladiella mougeotii</i> Lév	Powdery mildew	Victoria	F	M		APDD / VPRI- 17982a 6 records	Y
<b>Arthropods and pathogens recorded from other South African <i>Lycium</i> (Outside Australia)</b>									
?	Coleoptera: Chrysomelidae	<i>Chrysomela vigintiquatuorsignata</i> Thunberg	Leaf Beetle	South Africa	F		South African National Insect Collection Database	AcLG 101 AcLG 788 Adults and larvae feed vigorously	

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?	Coleoptera: Coccinellidae	<i>Epilachna eckloni</i> Muls.		South Africa	F		South African National Insect Collection Database	SN 2028; AcLG 680 AcP 8684	
<i>L. campanulatum</i> <i>L. afrum</i> <i>L. oxycladum</i> <i>L. acutifolium</i> <i>L. cinereum</i> <i>L. shawii</i> <i>L. europaeum</i>	Diptera:Tephritidae	<i>Neoceratitis lycii</i> (Coquillett)	Fruit fly	South Africa	Fr	P	South African National Insect Collection Database De Meyer & Freidberg 2012	AcP 43, 1322, 1509 Reared from host.	
<i>Lycium spp.</i> <i>L. horridum</i>	Hemiptera: Miridae: Phylinae	<i>Schuhistes lyciae</i> Menard		South Africa		O	Menard 2010 Fig. 10		
<i>Lycium spp.</i> <i>L. horridum</i>	Hemiptera: Miridae: Phylinae	<i>Schuhistes</i> <i>lekkersingia</i> Menard		South Africa		O	Menard 2010 Fig. 10		
<i>L. salinicola</i> <i>L. ?tetrandum</i>	Hemiptera: Triozidae	<i>Bactericera capensis</i> (Hollis)	Psyllid	South Africa			Burckhardt & Lauterer 1997	<i>L. salinicola</i> not currently considered valid	
<i>L. afrum</i> <i>L. europeum</i>	Hemiptera: Triozidae	<i>Trioza lienhardi</i> Burckhardt	Psyllid	North Africa Middle East Israel			Burckhardt & Lauterer 1997		
<i>L. afrum</i>	Hemiptera: Coccidae	<i>Pseudaonidia lycii</i> Brain	Scale	South Africa		?M	South African National Insect Collection Database	SN 2495 Syn <i>Ambigaspis</i> <i>lycii</i> Brain	
<i>L. oxycarpum</i>	Lepidoptera: Lasiocampidae	<i>Philotherma rosa</i> Duca	Lappet Moth	South Africa	?F	P	Kroon 1999		
?	Lepidoptera: Noctuidae	<i>Achaea lienardi</i> (Boisduval)	Fruit piercing Moth	South Africa	Fr	P	Kroon 1999		
?	Lepidoptera: Pylalidae	<i>Loxostege frustalis</i> Zeller	Karoo Caterpillar	South Africa		P	Kroon 1999		
?	Tetranychidae	<i>Tetranychus</i> <i>lombardini</i>	Spider mite	Africa, Australia, Madagascar,			South African National Insect Collection	Free State	Y

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				Indonesia					
?	Tenuipalpidae	<i>Brevipalpus phoenici</i> Geijskes	False spider mite	worldwide		P	South African National Insect Collection	Western Cape	Y
<i>L. cinereum</i>	Tenuipalpidae	<i>Tenuipalpus sophiae</i> Meyer	Mite	South Africa			South African National Insect Collection	Eastern Cape	
<i>L. hirsutum</i>	Tetranychidae	<i>Bryobia praetiosa</i> C. L. Koch	Clover mite	South Africa		P	South African National Insect Collection	Northern Cape	
<i>L. oxycarpum</i>	Tetranychidae	<i>Mixonychus acacia</i> Ryke & Meyer	Mite	Africa		P	South African National Insect Collection	Eastern Cape	
<i>L. afrum</i>	Pucciniales	<i>Puccinia afra</i> G. Winter	Rust fungus	Southern Africa, Spain			Berndt 2008 Mennicken et al. 2005		
<i>L. tubulosum.</i>	Pucciniales	<i>Puccinia lycii</i> Kalchbr.	Rust fungus	Southern Africa, Yemen			Mennicken et al. 2005 Berndt & Uhlmann 2006	Possibly synonymous with <i>P. turgid</i>	
<b>Arthropods recorded from other <i>Lycium</i> (Outside Australia)</b>									
<i>L. chinense</i>	Coleoptera: Coccinellidae	<i>Henosepilachna vigintioctomaculata</i> Fabricius	Hadda beetle	China	F, S, Flw	P	Alyokhin et al. 2012 Hori et al. 2011		
?	Coleoptera: Anthonominae	<i>Brachyogmus ornatus</i> Linell		USA, Mexico	Flw, Se	P	Burke 1976		
<i>L. depressum</i>	Coleoptera: Chrysomelidae	<i>Epitrix dieckmanni</i> Mohr		Middle East			Gök & Çilbıroğlu 2004		
?	Coleoptera: Ceutorhynchinae: Hypurini		Snout beetle	Palaeartic			Korotyaev 2008		
<i>L. chinense</i>	Coleoptera: Cerambycidae	<i>Annalists halodendri halodendri</i> Pallas <i>Annalists halodendri ephippium</i>		China			Liu et al. 2012		
<i>L. schweinfurthi</i>	Coleoptera: Chrysomelidae	<i>Cassida pellegrini</i> Marseu	Tortoise beetle	Israel, Cyperus		M	Pavlıček 1997		

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				Tunisia, Lebanon, Saudi Arabia					
<i>L. socotranum</i> <i>L. shawii</i>	Coleoptera: Chrysomelidae	<i>Cassida rothschildi</i> Spaeth	Tortoise beetle	Northern Africa, Yemen	F		Swietojska & Borowiec 2012		
<i>L. chilense.</i>	Diptera: Cecidomyiidae	<i>Panteliola chilense</i> Keiff. & Törg	Gall midge	S <sup>th</sup> America			Mani 1964		
<i>L. europaeum</i>	Diptera: Tephritidae	<i>Ceratitis capitata</i> Wiedemann	Medfly	Tunisia	Fr	P	Cayol 1996		
<i>L. turcomanicum</i>	Diptera: Tephritidae	<i>Neoceratitis asiatica</i> (Becker)	Fruit fly	Central Asia	Fr	P	De Meyer & Freidberg 2012		
<i>L. barbarum</i>	Diptera: Tephritidae	<i>Neoceratitis efflatouni</i> (Hendel)	Fruit fly	Middle East, Northern Africa	Fr		De Meyer & Freidberg 2012		
<i>L. cestroides</i>	Diptera: Agromyzidae	<i>Haplopeodes lycivora</i> Valladares	Miner	Argentina		?M	Salvo & Valladares 1997		
<i>L. ciliatum</i>	Diptera: Agromyzidae	<i>Haplopeodes</i> sp.	Miner	Argentina		?M	Salvo & Valladares 1997		
<i>L. barbarum</i>	Hemiptera: Triozidae	<i>Bactericera cockerelli</i> (Sulc.)	Potato/tom ato psyllid	North America	F	P	Percy et al. 2012, Burckhardt & Lauterer 1997		
<i>Lycium</i> sp.	Hemiptera: Triozidae	<i>Bactericera daedala</i> (Loginova)	Psyllid	Asia, Mongolia			Burckhardt & Lauterer 1997		
<i>L. ruthenicum</i> <i>L. depressum</i> <i>L. chinense</i> <i>L. barbarum</i>	Hemiptera Triozidae	<i>Bactericera gobica</i> (Loginova)	Psyllid	Asia, Mongolia China			Burckhardt & Lauterer 1997		
<i>L. barbarum</i> <i>L. cooperi</i>	Hemiptera: Triozidae	<i>Bactericera lobata</i> (Loginova)	Psyllid	North America			Burckhardt & Lauterer		

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							1997		
<i>L. depressum</i>	Hemiptera: Triozidae	<i>Bactericera petiolata</i> (Loginova)	Psyllid	Asia, North Africa, Middle East			Burckhardt & Lauterer 1997 Ouvrard 2012		
<i>L. afrum</i> <i>L. barbarum</i> <i>L. chinense</i> <i>L. depressum</i> <i>L. europaeum</i> <i>L. ruthenicum</i> <i>L. turcomanicum</i>	Hemiptera: Liviidae	<i>Diaphorina lycii</i> Loginova	Jumping lice	Europe, North Africa, Central Asia		O	Hodkinson 2009 Ouvrard 2012	<i>Syn Bactericera lycii</i>	
<i>L. americanum</i>	Hemiptera: Psyllidae	<i>Russelliana lycii</i> (Tuthill)		Argentina			Burckhardt et al. 2012		
<i>L. barbarum</i>	Hemiptera: Aphididae	<i>Myzus persicae</i> Sulzer	Green peach aphid	?	F, S	P	Maramorosch & Harris 1981	Records from unidentified <i>Lycium</i> in Australia (Tas). Listed by authors as <i>L. halimifolium</i>	Y
<i>L. barbarum</i>	Hemiptera: Diaspididae	<i>Lepidosaphes ulmi</i> (L.).	Oyster- shell scale	Hungary		P	Kosztarab 1959	Listed by authors as <i>L. halimifolium</i>	
<i>L. europaeum</i>	Lepidoptera: Coleophoridae	<i>Coleophora vigilis</i> Meyrick		Egypt			Li 2006		
<i>L. ruthenicum</i>	Lepidoptera: Coleophoridae	<i>Coleophora lycii</i> Falkovitsh		Uzbekistan.			Li 2006		
<i>L. barbarum</i>	Lepidoptera: Coleophoridae	<i>Coleophora neolycii</i> sp. n.		China	F	M	Li 2006		
<i>L. kopetdaghi</i>	Lepidoptera: Coleophoridae	<i>Coleophora synchrona</i> Falkovitsh		Iran	F, S	P	Li 2006		
	Lepidoptera: Coleophoridae	<i>Coleophora vigilis</i> Meyrick					Li 2006		
<i>L. kopetdaghi</i> <i>L. barbarum</i> .	Lepidoptera: Coleophoridae	<i>Coleophora mosasaurus</i> Falkovitsh		China (Ningxia), Turkmenista			Li 2006		

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				n					
<i>L. barbarum</i>	Lepidoptera: Coleophoridae	<i>Coleophora ningxiana</i> sp. n.		China			Li 2006		
<i>L. ruthenicum</i>	Lepidoptera: Coleophoridae	<i>Coleophora stegosaurus</i> Falkovitsh		Uzbekistan.			Li 2006		
?	Lepidoptera: Gelechiidae	<i>Tuta absoluta</i> Meyrick	Tomato leaf miner	Italy	F	O	Megido et al. 2013		
<i>L. chinense</i>	Lepidoptera: Gelechiidae	<i>Ilseopsis parki</i> sp. n.	Leaf miner	Korea	F	M	Povolny 1993		
<i>L. cestroides</i>	Hymenoptera: Braconidae: Doryctinae	<i>Allorhogas cordobensis</i> sp. nov.	Stem galler	Argentina	S		Martinez et al. 2011		
<i>L. chilense</i>	Hymenoptera: Braconidae: Doryctinae	<i>Allorhogas mendocinus</i> (Kieffer & Jörgensen)	Stem galler	Argentina	Bu		Martinez et al. 2008		
<i>L. afrum.</i> <i>L. barbarum</i>	Eriophyiidae	<i>Aceria eucricotes</i> (Nal.)	Web spinning mite	Europe, North Africa, Canary Is., USA			Lamb 1953		
<i>L. andersonii</i>	Eriophyiidae	<i>Aceria caulicecis</i> (Keifer)		USA			Ostojá- Starzewski 2009		
<i>L. europaeum</i> <i>L. afrum</i> <i>L. arabicum</i> <i>L. barbarum</i> <i>L. chinense</i>	Eriophyiidae	<i>Aceria eucricotes</i> (Nalepa)		S. Europe: Hungary, Italy. N. Japan, USA			Lamb 1953 Ostojá- Starzewski 2009		
<i>L. barbarum.</i>	Eriophyiidae	<i>Aceria kendalli</i> Baker		USA		M			
<i>L. chinense</i>	Eriophyiidae	<i>Aceria kuko</i> (Kishida)		Japan, China, South Korea	F			Alternative host: <i>Capsicum</i> <i>annuum</i> = <i>parawagnoni</i> (Kuang) = <i>tjyingi</i> (Manson) = <i>paramacrodonis</i> Kuang	

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<i>L. macrodon</i> <i>L. chinense</i>	Eriophyiidae	<i>Aceria macrodonis</i> Keifer		USA, Japan					
<i>L. pallidum</i>	Eriophyiidae	<i>Aceria pallida</i> Keifer		USA		M			
<i>L. cooperi</i>	Eriophyiidae	<i>Aceria wagnoni</i> Keifer		USA		M			
<i>L. chinense</i>	Eriophyiidae: Phyllocoptinae	<i>Phyllocoptes lyciumi</i> Song	Mite	China	F		Song et al. 2006	Vagrant	
<b>Pathogens recorded from other <i>Lycium</i> (Outside Australia)</b>									
<i>L. europaeum</i>	Pucciniales	<i>Puccinia turgida</i> P. Syd & Syd.	Rust fungus	Egypt, Israel, Pakistan Namibia			Mennicken et al. 2005		
	Pucciniales	<i>Puccinia spinulosa</i> Jørstad		Madagasc ar			Berndt & Uhlmann 2006		
?	Pucciniales	<i>Puccinia globosipes</i> Peck		New World			Berndt & Uhlmann 2006	= <i>Puccinia</i> <i>tumidipes</i> Peck	
?	Pucciniales	<i>Puccinia</i> <i>paradoxopoda</i> Speg.		New World			Berndt & Uhlmann 2006		
<i>L. barbarum</i>	Lasiochaeraceae	<i>Lasiochaeria</i> <i>strigosa</i> (Alb. & Schwein.) Sacc.		Europe		O	Checa & Barr 1999		
<i>L. intricatum</i>	Cucurbitariaceae	<i>Cucurbitaria varians</i> Hazsl.		Spain	S		Checa & Barr 1999		
<i>L. barbarum</i>	Herpotrichiellaceae	<i>Capronia inconspicua</i> (Munk) E. Müll		Spain	S		Checa & Barr 1999		
?	Pleosporales	<i>Microsphaeropsis</i> <i>olivacea</i> (Bonord.) Höhn		Asia, Europe, Australia	S	P	Damm et al 2008		Y
<i>L. europaeum.</i> <i>L. barbarum</i> <i>L. ovatum</i> <i>L. ruthenicum</i> <i>L. chinense</i>	Erysiphales	<i>Arthrocladiella</i> <i>mougeotii</i> Lév	Powdery mildew	Europe, North America, New Zealand, Serbia, Australia	F	O	Braun 1995 Cook et al. 1997 Rankovic & Vukojevic 2003 Susumu et al. 2003		

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							Ing 1990		
<i>L. chinense</i>	Glomerellaceae	<i>Colletotrichum</i> sp.	Anthrachnose		F		Koo 2008	Obligate symbionts. Sexual stage is <i>Glomerella</i>	
<i>L. barbarum</i>	Glomerellaceae	<i>Colletotrichum acutatum</i>	Anthrachnose	China	Fr		Sun et al. 2008		
<i>L. barbarum</i>	Glomerellaceae	<i>Colletotrichum gloeosporioides</i>	Anthrachnose	China	Fr		Sun et al. 2008		
<i>L. barbarum</i>	Glomerellaceae	<i>Colletotrichum dematium</i>	Anthrachnose	Korea	FR		Sun et al. 2008		
<i>L. barbarum</i>	Pleosporales	<i>Phoma sorghina</i> (Sacc.) Boerema, Dorenbosch & van Kesteren	Leaf spot	Argentina		P	Perelló & Moreno 2005	Host listed as <i>L. halimifolium</i>	
<i>L. barbarum</i>	Nectriaceae	<i>Fusarium concolour</i> Reinking	Medlar root rot	China	R		Shen et al. 2012		
<i>L. barbarum</i>	Nectriaceae	<i>Fusarium oxysporum</i> Schlechtend	Medlar root rot	China	R	P	Shen et al. 2012		
?	Cucurbitariaceae	<i>Cucurbitaria varians</i> Hazsl.		Europe	S		Sivanesan 1984		

1. F=foliage, S=stem, R=root, Fr=fruit, Se=seed, Bu=bud, Flw=flower.

2. P=polyphagous, M=monophagous, O=oligophagous

Appendix 5(a). Field sites surveyed for phytophagous organisms associated with *Lycium ferocissimum*

Site Number	State	Site Name	Date	Grid	E	N
1	Tasmania	Ross	10/5/13	55 G	0540121	5346185
2	Tasmania	Campbelltown	12/5/13	55 G	0540823	5357333
3	Tasmania	Richmond	07/5/13	55 G	0534908	5268305
4	Tasmania	Orielton	07/5/13	55 G	0545909	5261964
5	Tasmania	Berridale	10/5/13	55 G	0521031	5260433
6	Victoria	Koondrook	31/8/13	55 H	0239790	6061503
7	Victoria	Kerang	01/9/13	55 H	0766853	6034491
8	Victoria	Frankston	29/8/13	55 H	0338720	5782755
9	Victoria	Murchison	29/8/13	55 H	0357292	5947236
10	Victoria	Echuca	30/8/13	55 H	0282167	6006728
11	Victoria	Gunbower	30/8/13	55 H	0262026	6017740
12	Victoria	Cohuna	30/8/13	55 H	0240366	6045677
13	Victoria	Tatura	30/8/13	55 H	0341771	5982740
14	Victoria	Echuca	30/8/13	55 H	0295637	5998757
15	Victoria	Kerang	01/9/13	54 H	0763419	5999045
16	Victoria	Organ Pipes	01/9/13	55 H	0303566	5827687
17	Victoria	Bairnsdale	23/5/13	55 H	0546578	5811563
19	Victoria	Sale	23/5/13	55 H	0505961	5788032

African Boxthorn – feasibility of biological control

Appendix 5(b). Potentially phytophagous organisms associated with *Lycium ferocissimum* in Victoria and Tasmania

Order	Family	Species	Site Number	Abundance <sup>A</sup>	Organs attacked	Impact <sup>B</sup>	Accession numbers	Notes
<b>Lepidoptera</b>	Geometridae	Undetermined	4,16,19	R	leaves	N	LF7513 (1)	
	Tortricidae	<i>Epiphyas</i> sp.	15	R	?	N		1 pupa
	Psychidae	Undetermined	3	R	?leaves	N		1 larva
<b>Coleoptera</b>	Curculionidae	?Species 1 (small, long snout)	6	R	?	N	LF31813 (1)	
		? Species 2 (large)	10	R	?	N	LF30813 (5)	
	Anthicidae	Undetermined	1, 5, 6, 7, 8, 9,10,11,14,15	A,C	?leaves, flowers	N	LF29813 (3)	Abundant at most sites.
	Halticidae	?	6, 7, 9,10,13,14	R	?	N	LF30813(4)	Could be leaf or root feeder
<b>Hemiptera</b>	Aphidae	<i>Myzus persicae</i>	2, 7, 8	S	leaves	N	LF12513 (1) LF29813(2)	
	Psyllidae	<i>Aulacorthum solani</i>	9,12,14	A,C	leaves, stems	D	LF30813(2)	Significant impact on growth of branches. Severe chlorosis and stem stunting
		<i>Acizzia</i> sp.	6, 7,8,9,11,12,13,14,15, 16,				LF29813(1) LF30813(8) LF30813(10) LF30813(6) LF30813(1)	
							LF29813 (5)	
	Pseudococcidae	<i>Pseudococcus</i> sp.	8	C	stems	S	LF29813 (5)	Common in psyllid damaged branches
	Pentatomidae	<i>Nezara viridula</i>	5	R	?	N	LF10513 (1)	1adult
	Membracidae	? <i>Sextius</i> sp.	2	V, R	?stems	N		Vagrant
	Lygaeidae	<i>Nysius</i> sp.	2,10,11,12,14	R	stems	N	LF30813(3)	
	Flatidae	<i>Siphanta</i> sp.	8	R	stems	N		1 nymph only
	Miridae	<i>Taylorilygus</i> sp	5	R	?	N	LF10513(1)	3 adults
<b>Diptera</b>	Aleyrodidae	Undetermined	13	R	?	N		1 adult
<b>Psocoptera</b>	Psocidae	2 undetermined morphotypes	6, 7,10,12,14,15,16	C	?	N	LF30813(7)	Very common. Micro-epiphyte feeder
<b>Thysanoptera</b>	Thripidae	?Species 1	1,2, 4, 5, 7, 8, 9,10, 11,12,13	S, C	leaves	N	LF10513 (3) LF29813 (4)	
	Thripidae	? <i>Thrips imaginis</i>	19	C	leaves	N	LF23513(2)	
<b>Fungi</b>	Undetermined	Undetermined – Black spot	1, 8, 10,	C	leaves	N		
	Undetermined	Undetermined - White spot	7,1	R	leaves	N		
	Undetermined	Undetermined – Soft brown necrosis	2, 17	S	leaves	N		

**A:** A= abundant (often in high numbers), C= common (at most sites but in small numbers), S=sporadic (at a small number of sites, but sometimes in abundance), R= rare (few sites with few individuals seen), V=vagrant/ casual associate

**B:** K= capable of killing host, D= debilitates host, but recovery usually occurs, S= slight impact, N= negligible impact

Appendix 6. Stakeholders for consultation in the nomination of *Lycium* as a target for biological control

Agency	Address	Position
Department of Environment and Primary Industries	GPO Box 4440 Melbourne VIC 3001	Director Biosecurity Victoria
Department of Primary Industries, Parks, Water and Environment	171 Westbury Road PROSPECT TAS 7250	Director Invasive Species Branch
Department of Primary Industries, Parks, Water and Environment	1 Franklin Wharf Hobart TAS 7000	Director Biosecurity & Product Integrity Division
NSW Department of Primary Industries	NSW DPI, Locked Bag 21, Orange NSW 2800	Director Biosecurity
NSW National Parks Service	PO Box A290 Sydney South, NSW 1232	Director
Department of Agriculture, Fisheries and Forestry	GPO Box 46, Brisbane QLD 4001	Director Primary Industries
Department of National Parks, Recreation, Sport and Racing	PO Box 15187 City East Q 4002	Director Parks and Wildlife Service
Parks and Wildlife Commission of the Northern Territory	PO Box 496 Palmerston, NT 0831 Australia	Director
Department of Primary Industries and Fisheries	GPO Box 3000 Darwin, NT, 0801	Director Biosecurity and Product Integrity
Department of Agriculture and Food	Locked Bag 4 Bentley Delivery Centre WA 6983	Director Plant Biosecurity
Department of Parks and Wildlife	Locked Bag 104 Bentley Delivery Centre WA 6983	Director
Department of Primary Industries and Regions SA	GPO Box 1671 Adelaide SA 5001	Director Biosecurity SA
Department of Environment, Water and Natural Resources	GPO Box 1047 Adelaide SA 5001	Director National Parks
Plant Health Australia	Level 1, 1 Phipps Close DEAKIN ACT 2600	Director
Department of Agriculture, Fisheries and Forestry	GPO Box 858, Canberra ACT 2601	Deputy Secretary Biosecurity Australia
Nursery and Garden Industry Australia	PO Box 7129 BAULKHAM HILLS, BC, NSW 2153	Chief Executive Officer
National Farmers Federation	PO Box E10 Kingston ACT AUSTRALIA 2604	Secretary
Australian Quarantine and Inspection Service	GPO Box 858, Canberra ACT 2601	Director AQIS
Australian Honey Bee Industry Council	P.O. Box 4253 Raceview QLD 4305 Australia	Secretary
Greening Australia	333 Bennetts Road Norman Park QLD 4170	Secretary
CSIRO	CSIRO EcoSciences Precinct 41 Boggo Road Dutton Park QLD 4102 Australia	Director Biosecurity Flagship