

**Prospects for the Biological Control of Sydney golden wattle,
Acacia longifolia, using *Trichilogaster acaciaelongifoliae* and
*Melanterius ventralis***

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Summary

Project and Client

The prospects for using *Trichilogaster acaciaelongifoliae* (Andrews) Willd. (Hymenoptera: Pteromalidae) and *Melanterius ventralis* (Lea) (Coleoptera: Curculionidae) to control *Acacia longifolia* (Sydney golden wattle) in New Zealand were assessed for the Department of Conservation, Northland Conservancy. The work was carried out by Richard Hill on behalf of Landcare Research, Lincoln, in June 2005.

Objectives

- Research the feasibility of release of *Trichilogaster acaciaelongifoliae* and *Melanterius ventralis* for the biological control of *Acacia longifolia*.
- Estimate the total cost of the programme for the release of the agents.

Main Findings

- *Acacia longifolia* is native to the eastern seaboard of the Australian mainland, but has naturalised in many countries, and is a serious weed in South Africa.
- In New Zealand it occurs sporadically from Northland to Motueka, growing in dunes and dry coastal sites.
- It is a key weed in the Department of Conservation reserve at Kaimaumau swamp in Northland, threatening flora, fauna and ecological processes.
- *A. longifolia* is closely related to *A. sophorae* and *A. floribunda*, all of which were once subspecies of *A. longifolia*. Of the other species of the family Mimosaceae in New Zealand, only *A. melanoxylon* has significant economic or ecological value.
- There are no native species of the Mimosaceae in New Zealand. The closest relatives to *A. longifolia* in New Zealand are *Sophora*, *Carmichaelia*, *Clanthus* and *Montigena* species. These belong to the related family Fabaceae.
- Conflicts of interest in South Africa resulted in the release of seed-inhibiting insects only. Agents that attack other plant parts have not been assessed.
- This weed appears to be controlled in South Africa by a gall-forming bud wasp, *Trichilogaster acaciaelongifoliae*, and a seed-feeding weevil, *Melanterius ventralis*. Together, these agents can inhibit 90–100% of seed production in *A. longifolia*.
- The effectiveness of the two agents varies from place to place in South Africa. Published accounts suggest that control is not achieved in areas that are similar in climate to Northland, though recent comments suggest that control may be more uniform than published accounts suggest.
- On balance, Australia is recommended as the appropriate place in which to conduct research into the selection and safety-testing of potential natural enemies for *A. longifolia* in Northland.

Conclusions and Recommendations

A research programme is proposed based on the premise that the project should be approached from first principles. A survey should be undertaken in New Zealand to clarify what organisms are already present on *A. longifolia*. Assuming nothing of significance is found the control agents available in Australia should be reassessed. Control agents should be

sourced from sites that resemble Northland climatically, and New Zealand genotypes of *A. longifolia* must be susceptible to the selected agents in those sites.

Several tasks have been identified that would narrow the search for effective control agents, and clarify the prospects for effective biological control of *A. longifolia* in New Zealand:

- Determine, using the CLIMEX model, the areas of Australia within the natural range of *A. longifolia* that most resemble Northland.
- Determine, using molecular techniques, the origin in Australia of *A. longifolia* from South Africa and New Zealand.
- Directly test the susceptibility of New Zealand *A. longifolia* to Australian insect species by planting out and monitoring seedlings in Australia.
- Survey legume species adjacent to heavily infested *A. longifolia* plants in South Africa and Australia to search for non-target impacts.
- Plant those New Zealand native legumes that are available in Australia as well, and monitor their susceptibility to selected control agents.

The cost of a research programme to develop a biocontrol programme for *A. longifolia* is estimated at \$150–200,000 over two years.

1. Introduction

The prospects for using *Trichilogaster acaciaelongifoliae* (Andrews) Willd. (Hymenoptera: Pteromalidae) and *Melanterius ventralis* (Lea) (Coleoptera: Curculionidae) to control *Acacia longifolia* (Sydney golden wattle) in New Zealand were assessed for the Department of Conservation, Northland Conservancy. The work was carried out by Richard Hill on behalf of Landcare Research, Lincoln, in June 2005.

2. Background

Acacia longifolia (Andrews) Willd., Sydney golden wattle, is a shrub or small tree also known as sallow wattle or coastal wattle. *A. longifolia* once belonged to the subfamily Mimosoideae of the Fabaceae, the pea family, but is now generally placed in a separate family, the Mimosaceae.

A. longifolia is native to Australia (see Section 5 for detail). It was introduced to New Zealand as an ornamental, and naturalised before 1897 (Webb et al. 1988). It has become invasive here, occupying dune systems and disturbed habitats, modifying vegetation and ecological processes. It can grow to 7 m tall, and has a ‘weediness score’ of 26 and a ‘biological success rating’ of 12 (<http://docintranet/bioweb>). It particularly threatens regeneration patterns in native habitats recovering from the effects of fire. *A. longifolia* is occupying an increasing proportion of the better-drained parts of Kaimaumau Swamp (Hicks et al. 2001). It is too widespread for conventional control to achieve the desired conservation gains there, and even if control could be achieved, the threat of invasion from infestations in neighbouring dunes and gumlands is high. Hicks et al. recommended assessment of the feasibility of seed suppression of *A. longifolia* in New Zealand using the known, effective biocontrol agents, and completion of a cost–benefit analysis on a national basis to see whether such a project should proceed.

A. longifolia was introduced to South Africa from Australia as early as 1827 to stabilise sand dunes, but was also planted as an ornamental. As is the case in New Zealand, the source of the material planted in South Africa is not known. It became one of the most important invasive weeds endangering the floristically unique Cape Floral Kingdom – the Cape fynbos, or heathland (Fig. 1) (Dennill et al. 1999).

As well as being invasive weeds in South Africa, Australian wattle species are used there for timber, tannin and pulpwood products, and are commercially important plants (Adair et al. 2000). This has resulted in considerable opposition to the concept of managing wattles using biological control. Natural enemies that might affect growth rates or wood quality of species that some stakeholders value, such as *Acacia mearnsii* (valued as a source of tannin), have not been seriously considered. Although there are many insects available in Australia that have potential as biocontrol agents for *Acacia* species, only seed-feeding or seed-inhibiting insects (or highly host-specific diseases) have been considered so far.

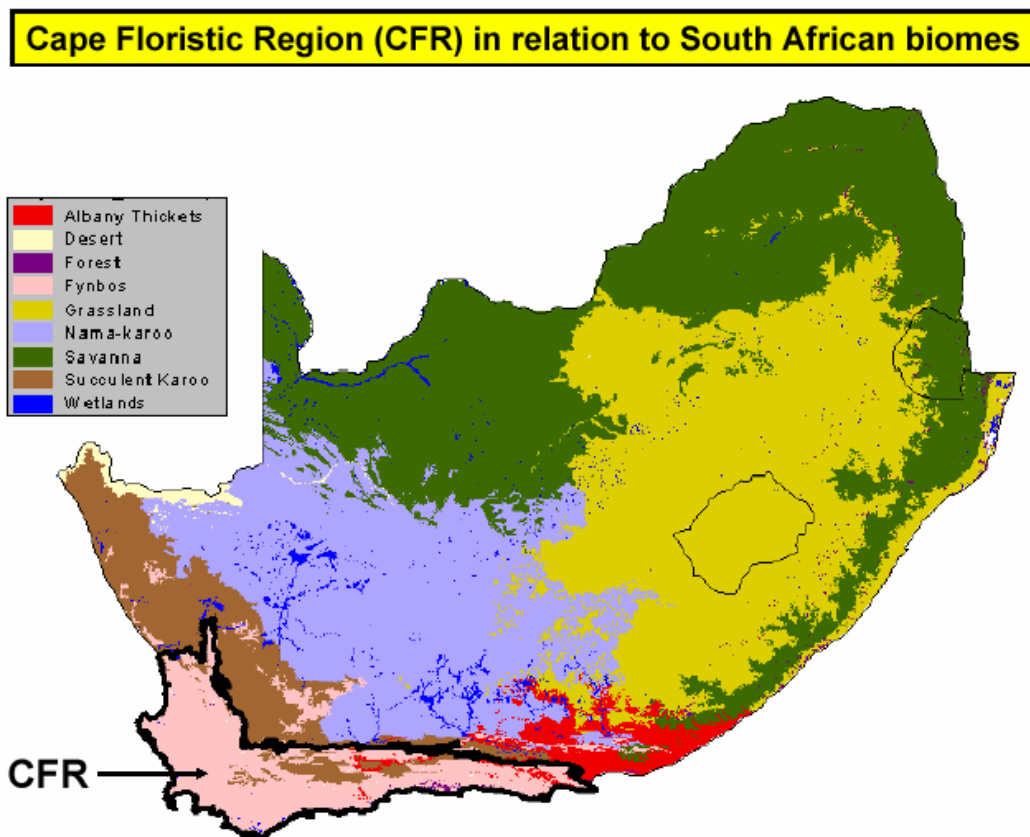


Fig. 1 The Cape floristic region, South Africa.

It is thought that control of *A. longifolia* has been achieved in South Africa by reducing seed production by 90–100% using two seed-inhibiting biocontrol agents, the gall wasp *Trichilogaster acaciaelongifoliae* Froggatt (Hymenoptera: Pteromalidae) and the seed weevil *Melanterius ventralis* Lea (Coleoptera: Curculionidae). It is claimed that these agents have reduced seed production, limited accumulation of seeds in the long-lived seed bank, and so reduced the ability of *A. longifolia* to recolonise disturbed habitats. In light of these claims, it is surprising to find that there are relatively few robust published accounts of the field performance of the agents (especially for *M. ventralis*; Dennill et al. 1999) and that the population dynamics of the interaction have not been measured (Donnelly & Hoffman 2004).

This report briefly summarises the known information about the biocontrol agents for *A. longifolia* and their performance in South Africa, and discusses the issues affecting the feasibility of transferring the biocontrol system to New Zealand.

3. Objectives

- Research the feasibility of release of *Trichilogaster acaciaelongifoliae* and *Melanterius ventralis* for the biological control of *Acacia longifolia*.
- Estimate the total cost of the programme for the release of the agents.

4. Sources of Information

This report is based largely on the scientific publications describing the successful control of *A. longifolia* in South Africa that are listed in the references. A Web search was also undertaken. Information was accessed from the CABI Crop Compendium and other databases. Information was sought from:

- Tony Gordon, Agricultural Research Council – Plant Protection Research Institute, Stellenbosch, RSA.
- Stefan Naser, Agricultural Research Council – Plant Protection Research Institute, Pretoria, RSA.
- Helen Braithwaite, Department of Conservation, Christchurch, New Zealand.

5. Distribution and Taxonomic Status of *A. longifolia*

5.1 Global distribution

The genus *Acacia* contains c. 1200 species, most native to Australia and Africa (Whibley 1980). *A. longifolia* is native to Australia. With the exception of one or two outlying records in Queensland and the Northern Territory, *A. longifolia* occupies a coastal distribution in New South Wales, and Victoria south of latitude 27°S. *A. longifolia* is extensively cultivated for ornamental purposes, and is presumably adventive in West Australia, South Australia and Tasmania. It appears to grow where rainfall exceeds 800 mm annually (Fig. 2), and where average maximum temperature does not exceed 22°C (Fig. 3). The climate requirements of this species have not been examined in detail, but the distribution in Australia suggests that *A. longifolia* potentially has a wide distribution in New Zealand, especially in coastal habitats.

A. longifolia was introduced to South Africa in 1827 to stabilise drift sands on the Cape Flats. It has since become an important invader of mountain and river ecosystems in the Southern and Southwestern Cape Province (Dennill & Donnelly 1991). *A. longifolia* was also introduced to Portugal to stabilise dunes. Marchante et al. (2003) concluded that this species changes community composition and structure of the dune ecosystems promoting monospecific communities, decreasing species richness and increasing plant cover. It has also been recorded in the USA (CA, FL), Dominican Republic, Argentina, Brazil, Colombia, Uruguay, Italy, Spain, India, Java, Sri Lanka, Kenya, Mauritius and La Réunion (ILDIS 2005).

5.2 New Zealand distribution

A. longifolia appears to have naturalised in New Zealand before 1897 (Webb et al. 1988). It is not recorded whether founding plants were obtained directly from Australia, or through another source such as Kew Gardens. It is established locally in Northland, especially near Kaitaia. It is locally established in Auckland City, and is also reported from Ruakura and Wellington City. In the South Island it is established at Motueka Inlet (Webb et al. 1988). *A. longifolia* occupies waste land and scrubland, especially in coastal areas. It is not generally

regarded as a weed of importance, but is a key weed in the conservation of Kaimaumuau swamp (Hicks et al. 2001).

The Department of Conservation's 'Bioweb' adds the following records:

- Pollen Island, Rangitoto Island (Auckland)
- Omaha Wetland Forest (Warkworth)
- Lake Okareka, Rotorua
- Makaramea Scenic Reserve (Gisborne)
- Waioeka Gorge (Opotiki)
- Bay of Islands, Puketi Forest, South Hokianga (Bay of Islands)
- North Taranaki Coast
- Edward's Bush Kopane, Himatangi Beach (Palmerston North)
- Coast at Castlecliff, Lake Kaitoke (Wanganui).

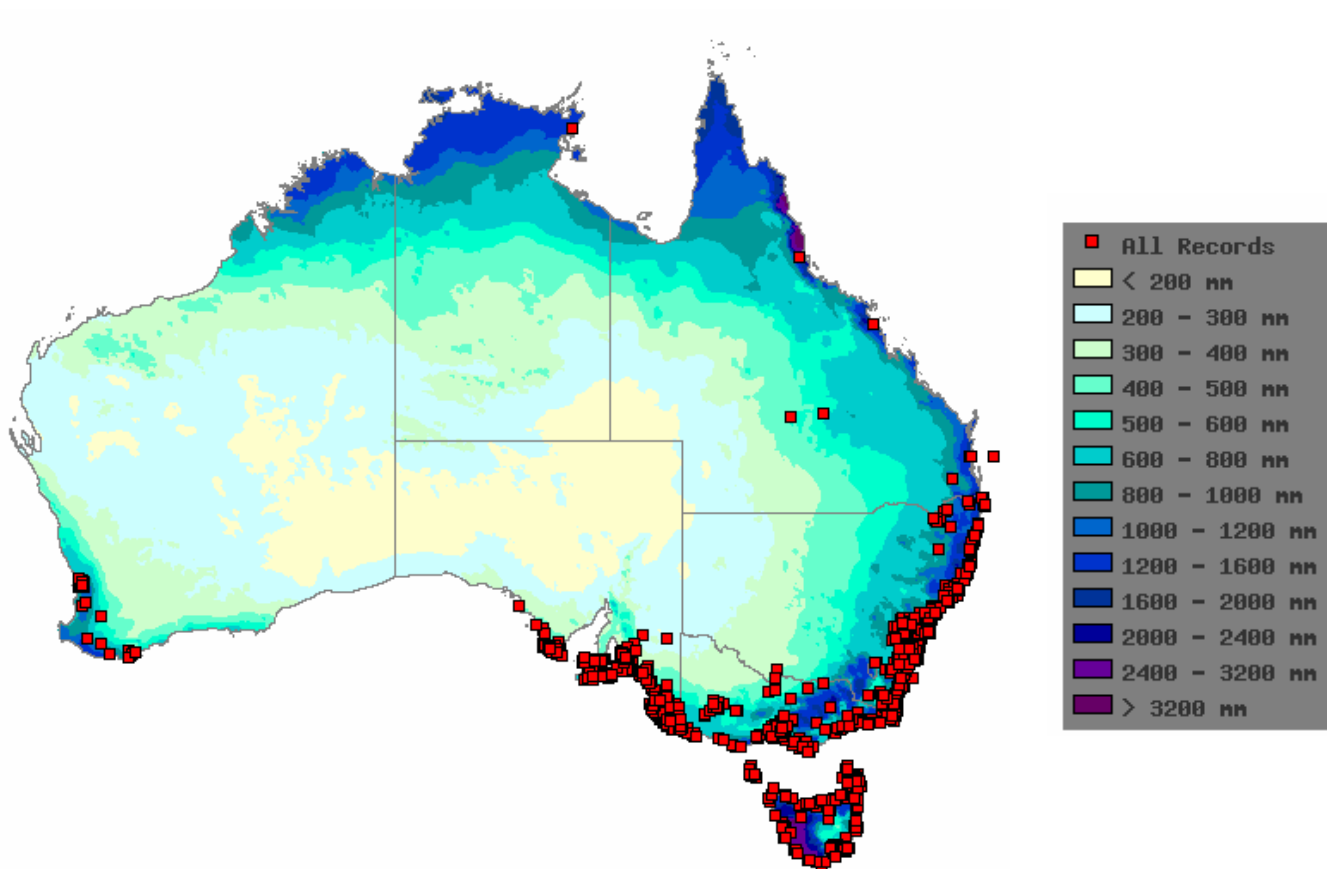


Fig. 2 Distribution of *Acacia longifolia* in Australia (1756 records) plotted on annual rainfall distribution (source: Royal Botanic Gardens, Melbourne, 'Australia's Virtual Herbarium', <http://www.rbg.vic.gov.au/cgi-bin/avhpublic/avh.cgi>).

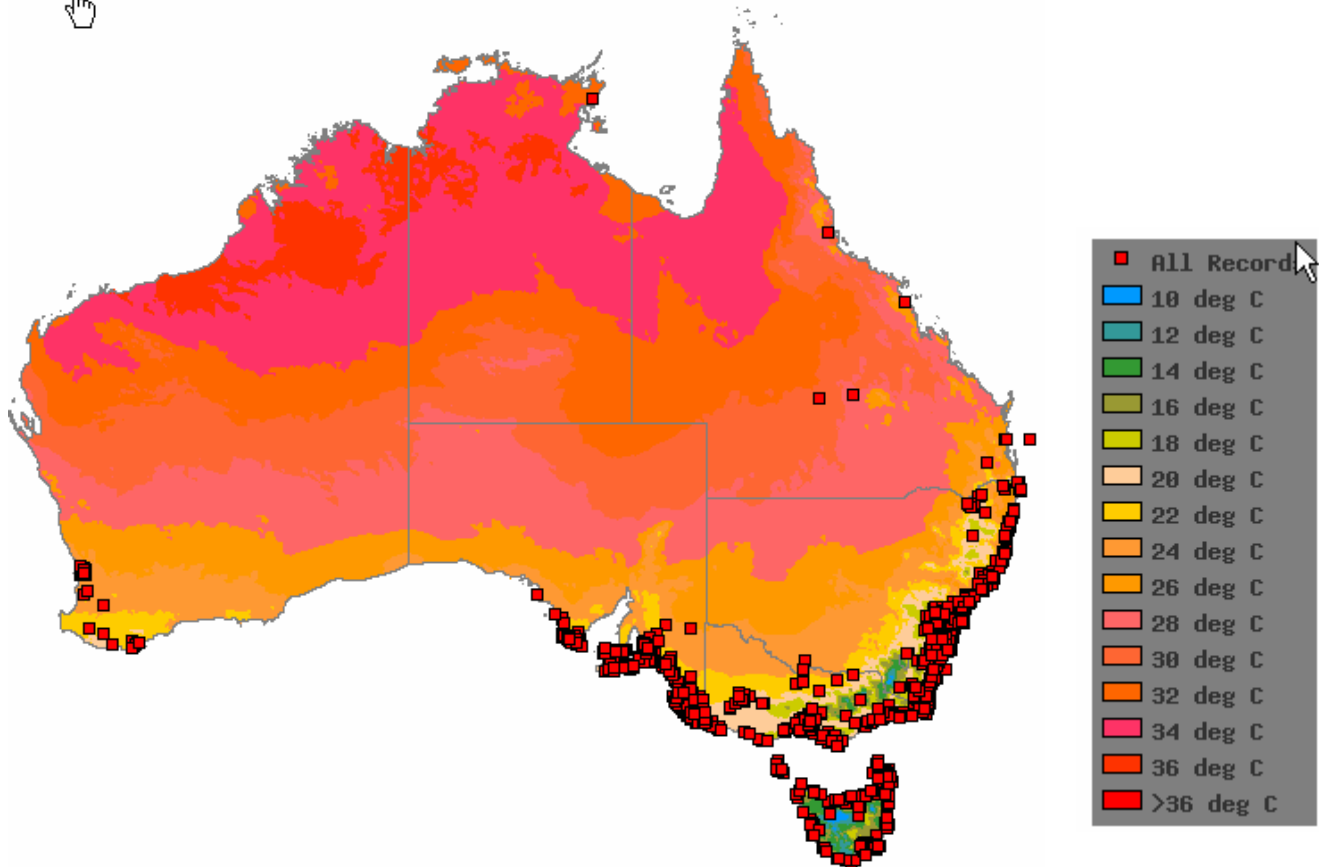


Fig. 3 Distribution of *Acacia longifolia* in Australia (1756 records) plotted on average maximum temperature distribution (source: Royal Botanic Gardens, Melbourne, 'Australia's Virtual Herbarium', <http://www.rbg.vic.gov.au/cgi-bin/avhpublic/avh.cgi>).

5.3 Taxonomic position of *Acacia longifolia* in New Zealand

Acacias once belonged to the subfamily Mimosoideae of the Fabaceae, the pea family, but are now generally placed in a separate family, the Mimosaceae. *A. longifolia* and *A. sophorae* (Labill.) C. Martius (formerly *A. longifolia* var. *sophorae*) are both cultivated in New Zealand gardens. Nearly all naturalised material can be reliably referred to as *A. longifolia* but *A. sophorae* occasionally escapes from cultivation (Webb et al. 1988). They can be distinguished by the following features (Orchard & Wilson 2001):

<i>longifolia</i>	Phyllodes 5–20 cm long and 5–15 mm wide, mostly broadest near or below middle, mostly thin and pliable, commonly narrowing gradually towards apex; pods mostly straight (near-coastal tracts and hinterland in Australia)
<i>sophorae</i>	Phyllodes 5–12 cm long and 10–30 mm wide, often thick and sometimes fleshy, mostly broadest near or above middle, commonly narrowing ±abruptly towards apex; pods mostly coiled or contorted (mostly coastal in Australia).

There is a wide range of other *Acacia* species in New Zealand, most of them cultivated and sold as ornamental species, for soil conservation, as bee fodder, for woodlots, and potentially

as bioenergy sources. With one exception, none of these uses is significant to the New Zealand economy. *Acacia melanoxylon* is grown widely as a specialty hardwood tree. It is arguably the most valuable of the species, although it makes up less than 2% of the exotic plantation in New Zealand.

New Zealand has no native species in the tribe Acaciae, or the family Mimosaceae. The most closely related native and endemic genera belong to the Fabaceae are (Heenan 1998; Heenan et al. 2001):

- *Sophora*, 9 species
- *Carmichaelia*, 23 endemic species
- *Montigena novae-zealandiae* (Hook.f.) Heenan
- *Clanthus maximus* Colenso, *C. puniceus* (G.Don) Sol. ex Lindl.

Wagstaff et al. (1999) used a phylogenetic analysis to show that *Clanthus*, *Carmichaelia* and *Montigena* formed a single monophyletic clade.

A number of other genera within the Fabaceae such as clovers, peas, beans etc. have major economic value in New Zealand.

6. Current State of Biological Control of *A. longifolia* in South Africa

6.1 *Trichilogaster acaciaelongifoliae* Froggatt (Hymenoptera: Pteromalidae)

The biology and ecology of *T. acaciaefoliae* in South Africa is summarised by Dennill & Donnelly (1991) and Dennill et al. (1999).

T. acaciaefoliae is a small gall-forming wasp (Pteromalidae). It is largely parthenogenetic, males being relatively rare. However, Nesar (1985) reported that the proportion of males varied between populations in Australia. There is one generation each year. Adult females emerge from spring until midsummer (October–January). Each wasp survives only about 3 days but in that time lays around 400 eggs into the buds that will become inflorescences in the following spring and summer. Although most prevalent on reproductive buds the wasp sometimes attacks vegetative buds, limiting shoot growth and biomass accumulation (Nesar 1982). There is evidence that this attack on vegetative buds is related to a partial second generation (Tony Gordon, pers. comm.). The eggs hatch in winter, and the young larvae induce the plant to produce a gall instead of an inflorescence (or a branch). Each larva forms a cell within the gall, feeds on the fleshy interior of the gall, and pupates there. Galling of a reproductive bud prevents the development of the inflorescence, and no seeds form.

In eastern Australia *T. acaciaelongifoliae* has been recorded from *Acacia longifolia* var. *longifolia* and *A. l.* var. *sophorae* (Nesar 1982). These variants are now considered to be full species (Webb et al. 1988). *T. acaciaelongifoliae* has also been reared from galls on *A. floribunda*, which was previously also classified as a variant of *A. longifoliae*. There is also one unconfirmed record from *A. implexa*. We can conclude that *T. acaciaefoliae* is highly host-specific, and probably restricted to three very closely related host plant species (Nesar 1982, 1985).

Froggatt noted that in its Australian home range, wasp galls could sometimes suppress seeding by 100%, but this effect was patchy, presumably because wasp numbers were usually regulated to below outbreak levels by parasitoids and predators (Dennill & Donnelly 1991). Following its release in South Africa, *T. acaciaelongifoliae* was distributed widely, and spread rapidly from these point sources (Dennill & Donnelly 1991). It does not appear to have the patchy effectiveness recorded by Froggatt. Parasitism has been recorded in South Africa, but is relatively rare (Dennill & Donnelly 1991).

Host specificity tests were conducted in South Africa from 1977 to 1980 (Neser 1982). Tests were conducted on a range of potted plants in cages, including 12 Australian and seven African *Acacia* species. Ability to attack both reproductive and vegetative buds was tested. Females were occasionally observed to probe buds of *A. melanoxylon* in tests, but no galls developed on any plants other than *A. longifolia*. *Paraserianthes lophantha* was not tested. Since its release in South Africa, *T. acaciaelongifoliae* has increased to enormous numbers. Trees of *A. melanoxylon* and *P. lophantha* growing in the vicinity of heavily galled *A. longifolia* have been observed occasionally to carry small, sparsely distributed galls (Dennill et al. 1999). Effects have proven to be negligible and temporary (Dennill et al. 1999). No other non-target attack has been observed in the field. An indigenous parasitoid, *Pseudotorymus* sp., has been recorded attacking 21.3% of gall wasp larvae in the Western Cape, and 60–80% in the Eastern Cape, but parasitism does not appear to limit the effectiveness of the wasp as a biocontrol agent (Dennill et al. 1999).

Pod production on trees is disproportionately inversely related to the proportion of branches galled, so when 50% or more branches on a tree are galled, pod production is commonly reduced by 90% or more. Heavy gall formation also causes the abscission of mature phyllodes and shoot dieback. This reduces growth rate and biomass accumulation in the tree. Dennill (1988) claimed that the wasp had a disproportionately negative effect on plants because gall formation was more resource intensive than normal growth and reproduction, debilitating the plant. When *A. longifolia* plants are under environmental stress such as moisture deficit, heavy galling by *T. acaciaelongifoliae* can kill plants (Donnelly & Hoffman 2004).

This insect has markedly reduced the seed production of *A. longifolia* in South Africa, but high levels of control are not universal. Dennill & Gordon (1990) analysed where *T. acaciaelongifoliae* was most effective in South Africa. Areas in which *A. longifolia* grew were assigned to categories using the climate classification of Walter & Leith (1960). Heavy galling was largely restricted to *A. longifolia* plants growing in those coastal areas of the Southwestern and Southern Cape Province that have a Type IV climate (Fig 4.). This is described as a Mediterranean climate, with winter rains, and a short period of aridity in midsummer. Galling was much less intense and less effective in the hotter inland valleys that have a Type III climate. This is described as a subtropical climate, and in this case with long periods of aridity in midsummer. Dennill & Gordon (1990) believed that the higher temperatures in the inland areas caused mortality of *T. acaciaelongifoliae* eggs, because even plants growing in riverine situations with adequate water had very few galls. They did not believe that the lack of galls was related to a climate-driven lack of synchrony between the presence of suitable bud primordia and ovipositing adults (Tony Gordon, Agricultural Research Council – Plant Protection Institute, South Africa, pers. comm.).

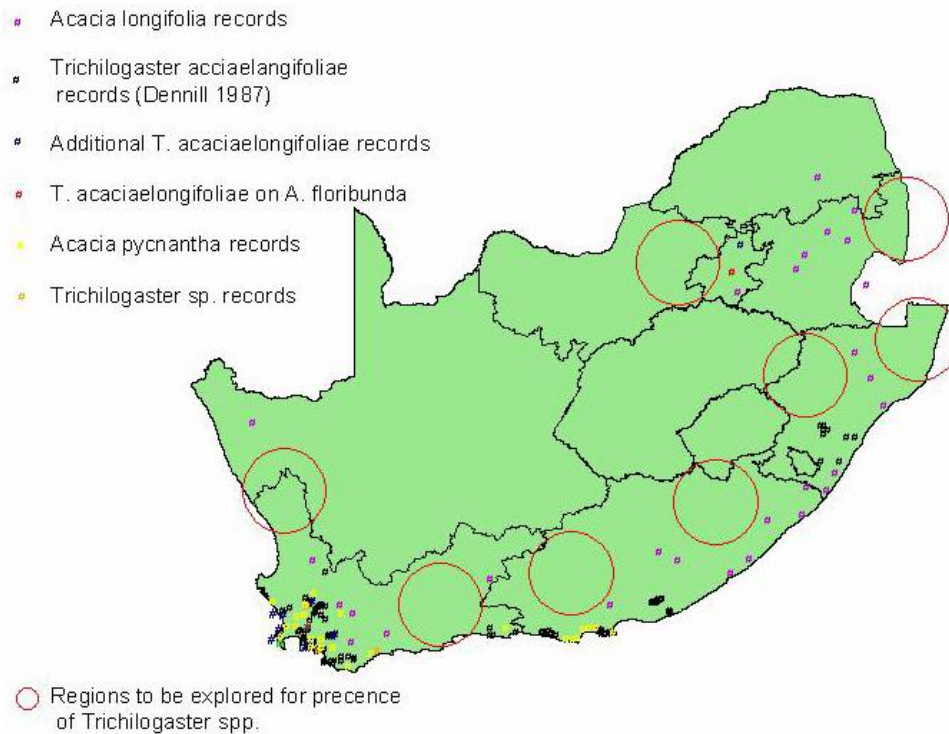


Fig. 4 Distribution in South Africa of *Acacia longifolia* (purple) and *Trichilogaster acaciaelongifoliae* (dark blue). Ruan Veldtman unpublished (<http://academic.sun.ac.za/botzoo/space/veldtman/>)

6.2 *Melanterius ventralis* Lea (Coleoptera: Curculionidae)

The biology and ecology of *M. ventralis* in South Africa is summarised by Dennill & Donnelly (1991), and their paper provides a review of knowledge to 1990.

A year-long survey of the insects attacking *A. longifolia* in Australia was conducted by van den Berg (Neser 1985; Dennill & Donnelly 1991). Several insects that showed promise as control agents for *A. longifolia* were selected for further study. Amongst these was the seed pod weevil *Melanterius ventralis*.

Melanterius species are small (3–4 mm) black weevils (Curculionidae). A number of species of this genus are known in Australia. *Melanterius* species are generally monophagous, or are restricted to one or two closely related species of *Acacia* (Dennill & Donnelly 1991).

Weevils feed in *Acacia* flowers, and then mate in September and October. Females chew through the developing pod wall and lay eggs singly on seeds. Larvae develop within the seeds, and emerge after 6 weeks. If the pods are still on the tree, the weevil larva chews through the pod wall to escape (creating a characteristic emergence hole), falls to the ground and pupates in the litter. After 6–8 weeks (in mid to late January in South Africa) the adult weevils emerge from the soil. Adults remain immature and inactive until August, when plants begin to flower. Pods are present on trees for only a short period each year, allowing only one generation annually. Some weevils may survive to lay eggs for a second year (PPRI 2005).

M. ventralis was selected and introduced to South Africa before it became clear that *T. acaciaelongifoliae* would be so successful at reducing seed production of *A. longifolia* there (Neser 1985; Dennill & Donnelly 1991). Host-range tests were conducted from 1983 to 1985 before *M. ventralis* was introduced in 1985 (Donnelly 1992). Pods form only on mature plants of African *Acacia* species, and so tests could not be conducted on plants indoors. Instead, ‘no choice’ host-range tests were conducted by bagging weevils on growing stems in the field. Ten Australian species of the Mimosaceae naturalised in South Africa were tested, as well as six *Acacia* species and six legume species indigenous to Africa. Six legumes of commercial importance such as beans, peas, lupins and lucerne were also tested. *A. longifolia* was the only species that supported any adult feeding or oviposition on bagged branches. *M. ventralis* appears to be monospecific (Donnelly 1992). Despite subsequent intense research into the ecology and control of a number *Acacia* species in South Africa, there are no published records of *M. ventralis* attacking other plant species (Dennill et al. 1999).

M. ventralis was introduced to South Africa from Australia beginning in 1985, and established readily (Dennill & Donnelly 1991). *T. acaciaelongifoliae* destroys most flower buds and reduces seed set by more than 95%, leaving little resource for weevils to utilise. Some pods continue to develop, especially on vigorously growing plants that are not under moisture stress. *M. ventralis* appears to be adept at finding these rare pods. Donnelly & Hoffman (2004) showed that females were able to detect pods already attacked by conspecific weevils, limiting competition and egg wastage. They claimed that percent seed damage was not related to the number of seeds available, which suggests that heavy seed crops will not exhaust the capacity of weevil populations to suppress them. They also found that weevils spent more time on the branches with the most pods, suggesting good searching ability. These characteristics all suggest that *M. ventralis* is an efficient seed predator, and a potentially important complementary control agent to *T. acaciaelongifoliae*. Occasional parasitism of *M. ventralis* has been recorded at 10 sites, but has averaged only 2.1% of weevil larvae (Dennill et al. 1999). Dennill et al. (1999) reported that the insects were spreading naturally only slowly from release sites, but that infestation rates ranged from 14.9 to 79.5% of pods just three generations after release.

7. Issues for any Future Biological Control Programme for *A. longifolia* in New Zealand

7.1 Are these two agents suitable?

Biological control of weeds using seed feeders affects plant populations in two ways. The rate and intensity of a weed invasion is a function of seed production. If fewer seeds are produced, establishment distant from the source of infestation will be less likely, and spread of the core infestation will be slower. There seems little doubt that *T. acaciaelongifoliae* and *M. ventralis* have almost eliminated seed production by *A. longifolia* in many parts of South Africa, and that they are performing this role there. It is less clear what effect these two seed-inhibiting species will have on the long-term population dynamics of existing populations of *A. longifolia* in South Africa (Donnelly & Hoffman 2004). Dennill & Gordon (1990) reported that the wasp caused some mortality in trees at 30% of sites, and definitely reduced biomass of the weed. This is not sufficiently severe to affect long-term population dynamics. Whether

population suppression is occurring may only become clear once the long-lived seed bank declines to a point where recruitment fails to compensate for mortality of parent shrubs. This effect may not be seen for decades where *A. longifolia* has been present for any length of time and long-lived seed banks already exist. While the effect of the two agents on the population dynamics of *A. longifolia* in South Africa has not been measured, there is strong anecdotal evidence that the weed is less important than it once was (Donnelly & Hoffman 2004).

The sequential nature of attack means that the two agents complement each other. *T. acaciaelongifoliae* is the most effective agent, and attacks reproductive structures at the early stages, suppressing a high proportion of buds altogether. Pods that form even after gall wasp attack are then susceptible to *M. ventralis*. The activity of the gall wasp varies from place to place and probably from year to year. *M. ventralis* will be able to compensate in part for variation in the level of gall wasp attack and add stability to control. If both agents were to be introduced to New Zealand, fewer seeds would be produced annually than if either agent was introduced alone.

A. longifolia is of limited distribution in New Zealand, both geographically and locally. Reducing seed production would limit the accumulation of a long-lived seed bank under existing plants and slow the spread of existing populations.

If effective, biological control has the added advantages of being selective amongst sensitive native vegetation. Control would be self-sustaining from year to year, and largely self distributing. Although galling by *T. acaciaelongifoliae* has been recorded to debilitate and even kill plants, it is unlikely that these agents would significantly affect the existing crop of *A. longifolia* plants.

7.2 Are any other agents available?

Because of conflicts of interest between those who wish to suppress wattles and those who wish to use them, only seed-inhibiting insects have been considered as biocontrol agents for *Acacia* species so far (Dennill et al. 1999). *Acacia* species are not so highly valued in New Zealand and there is no implacable conflict of interest. There seems to be no impediment to seeking biocontrol agents that damage vegetative structures, stems trunks or roots.

Although *T. acaciaelongifoliae* and *M. ventralis* appear to be effective control agents for *A. longifolia* in South Africa, there has been considerable research to find equally effective agents to inhibit seed production of other weedy wattles. A by-product of these studies has been the identification of additional species that attack *A. longifolia*. Notable amongst these are the cecidomyiid fly *Dasineura acaciaelongifoliae* (Skuse) (Adair et al. 2000; Kolesik et al. 2005), and seed-feeding eurytomid wasps *Bruchophagus* spp. (Neser & Prinsloo 2004). Van den Berg identified other species that attack *A. longifolia* in Australia (e.g. van den Berg 1982, see Dennill et al. 1991). The full array of potential biocontrol agents for *A. longifolia* should be identified from the literature, and assessed before finally confirming the direction of any future biological control programme.

7.3 Is the New Zealand climate suitable for these agents?

T. acaciaelongifoliae appears to be most effective in the coastal areas of the Southern Cape Province of South Africa that have a mild Mediterranean climate (Dennill & Gordon 1990). The host plant appears to produce galls most abundantly in areas where there is a (short)

period of aridity in midsummer. These climates are categorised by Walther & Leith (1960) as Type IV climates. Galls are less abundant in hotter inland climates.

Walter & Leith (1960) described warm temperate, humid climates, with relatively even rainfall and no arid period, as Type V climates. Dennill & Gordon (1990) did not comment on the performance of the wasp in Type V climate areas, but from the Figures presented in their paper, it appears that the agent did not perform well in this climate type. The margin between high wasp impact and lesser impact coincides approximately with the margin between Type IV and Type V climate in South Africa (Dennill & Gordon 1990). The pattern of infestation observed by Dennill & Gordon (1990) apparently still holds today. Figure 4 shows the distribution of *A. longifolia* in South Africa, and the sites at which *T. acaciaelongifoliae* appears to be active. Control is still being achieved largely on coastal areas, and not inland. This suggests either that *T. acaciaefoliae* cannot build to large enough numbers inland in South Africa to produce many galls, or that *A. longifolia* plants growing in a Type V climate, without summer water stress, do not respond to wasp attack by producing such large or numerous galls.

The predominant climate type in the North Island of New Zealand is Type V, with some variants (Walter & Leith 1960). On existing knowledge there does not appear to be a close match between target areas of New Zealand, such as Northland, and the areas in South Africa where *T. acaciaelongifoliae* is known to be effective. However, Stefan Naser (pers. comm.) and others contend that this interpretation is outdated, that the impact of the agents in South Africa is understated, and that adverse effects on *A. longifolia* are more prevalent than formal records suggest. Dr Naser suggests that South African *T. acaciaelongifoliae* are sufficiently plastic to thrive in the New Zealand climate. This would need to be confirmed before committing significant resources to South Africa as the source of agents.

7.4 Are *T. acaciaelongifoliae* and *M. ventralis* host specific?

Gall-forming wasps such as *T. acaciaelongifoliae* are renowned for being highly host-specific. In its home range, this wasp has only been known to form galls on three closely related (and previously conspecific) species: *A. longifolia*, *A. sophorae*, and *A. floribunda*. Host range tests reported by Naser (1982) were detailed, but were restricted to a range of *Acacia* species of Australian and African origin. No galls were recorded on any plant except the target, confirming the extensive observations in the home range (Dennill et al. 1991). *T. acaciaelongifoliae* was never tested against economic legumes, but the possibility of attack on herbaceous legumes is so remote that testing need only be limited. Tests on *Chamaecytisus palmensis* may be necessary.

Acacia species were once assigned to the subfamily Mimosoideae of the Fabaceae, but are now placed in the family Mimosaceae. *A. melanoxylon* is a valued timber tree for New Zealand foresters. Occasional galls have been discovered on this non-target host in South Africa, and it would be important to assess the significance of the risk to this species if *T. acaciaelongifoliae* was proposed for introduction to New Zealand. Other *Acacia* species are planted in New Zealand either as soil protection plants, or minor ornamental species. Several are minor weeds. It is unlikely that any would be considered of major economic or ecological value.

It is certain that *T. acaciaelongifoliae* would attack *A. longifolia*, *A. sophorae*, and *A. floribunda* in New Zealand but attack on any other non-target species is highly unlikely.

M. ventralis was tested on a range of closely related *Acacia* species, and related economic legumes in South Africa. Like *T. acaciaelongifoliae* it was essentially monophagous on *A. longifolia* (Donnelly 1992).

Even without further research, it is clear that the risk posed by the control agents to valued plants in New Zealand would be minimal. There is scientific justification to claim that no further host-range testing is required for either agent, but it is doubtful whether this would be acceptable to stakeholders or regulatory authorities. The species of the family Fabaceae indigenous to New Zealand belong to four genera: *Sophora*, *Clanthus*, *Carmichaelia*, and *Montigena novae-zealandiae*. Wagstaff et al. (1999) showed that *Clanthus* and *Carmichaelia* had a common lineage, and are close to *Montigena*. This should limit the number of plants from this grouping that require testing. Any host-range tests could therefore be restricted to 5–10 species, mostly comprising New Zealand native legumes.

Host-range tests for these agents will be technically challenging. *T. acaciaelongifoliae* females lay eggs into developing buds that remain in situ for 8–10 months before developing. Providing plants with reproductive buds for oviposition and/or development tests and then maintaining healthy plants for this period in secure containment would be difficult. Oviposition tests using *M. ventralis* could be conducted on detached pods. It would not be possible to present pods in situ on growing plants. To overcome these problems, tests should be conducted outdoors in South Africa or Australia as far as possible. Field surveys could also elucidate the natural host range of the agents.

7.5 Is the source of the agent important?

Successful biological control requires that agents establish, and then achieve populations that are large enough to adversely affect the target plant. The chances of this are greatest when

- the majority of egg-laying female agents are present at the time when the plant bears high-quality, susceptible structures on which the agent can lay eggs, and when
- climatic conditions favour the survival and normal behaviour of the agents.

The life history of a plant is driven by the interaction between plant physiology (or genotype) and climate, while insect life history is largely driven by climate. Some plant genotypes can also be resistant or tolerant to insect attack. Choosing agents to ensure synchrony of these processes can sometimes be difficult.

There have been many examples where populations of control agents transferred from the home range to the target range have failed, probably due to the lack of compatibility or developmental synchrony between agent and weed. This can be overcome either by ensuring that the agent population originates from the same region as the plant genotype, or by sourcing agents from a sufficiently large gene pool or range of sources that there is enough variation in agent phenology to cover variation in the life history of the target weed.

There are two possible sources for founding populations of *T. acaciaelongifoliae* and *M. ventralis*; South Africa or Australia. *M. ventralis* females are long-lived, but cannot become reproductive until females feed on *A. longifolia* pollen (Donnelly 1992). Whenever *A. longifolia* flowers, the life histories of plant and weevil are automatically synchronised. There are no literature records of populations of *A. longifolia* being differentially acceptable to *M. ventralis*. New Zealand populations should be susceptible to weevils from any source,

as long as the climatic conditions match those in Northland, and weevils can survive and perform well there.

Unlike the weevil, *T. acaciaelongifoliae* adults only last 2–3 days, and in that time must find *A. longifolia* flower buds at the correct stage to attack. Such buds are present for less than a month each year. In this case, synchrony between high wasp populations and peak susceptibility of buds is crucial to the successful suppression of seed production.

Neser (1985) reported that the incidence and severity of *T. acaciaelongifoliae* attack in Australia seemed to vary from population to population. Sometimes single plants in a population were heavily galled compared with neighbouring trees. He rightly suggested that differential parasitism and predation in Australia could yield this pattern. Variation might also be explained by the physiological state of the plant during gall formation. The frequency of males in Australian populations of this largely parthenogenetic species also varies (Neser 1985). These observations suggest significant genotypic variation between wasp populations. There is a possibility that genotypic variation exists both in susceptibility amongst trees and host-finding capacity amongst populations of gall wasps. If this is so, the high level of seed suppression observed in South Africa may reflect a serendipitous match between weed and gall wasp genotypes.

A. longifolia was introduced to South Africa as early as 1827, and the source of the seed is not known. The wasps released in South Africa were sourced from at least five sites from the east coast of Australia, including a population reared from *A. floribunda* in Tasmania (Neser 1985). This is a wide genotypic pool, but it is not known whether wasps from all provenances have established in South Africa, or where. If agent or weed genotype is important in the quality of control in South Africa, then it cannot be assumed that New Zealand *A. longifolia* would be controlled by gall wasps sourced from there. The options available to determine this are to introduce the agent to New Zealand and assess it in situ, plant *A. longifolia* of New Zealand origin in South Africa or Australia and directly measure levels of attack, or ignore South Africa and select new wasp populations from one or more Australian sites with climates similar to that of Northland.

8. Conclusions and Recommendations

8.1 Steps toward biological control of *A. longifolia* in New Zealand

The steps in a potential biological control programme for *A. longifolia* involving two control agents would be as follows:

1. Survey plant in New Zealand to check what is already here
2. Select control agents
3. Complete safety-testing
4. Apply for permission to release agents
5. Import, quarantine, rear and release agents
6. Monitor outcomes.

Selection and safety-testing of control agents could be completed either in South Africa or in Australia. On balance, Australia is recommended as the best site for research into the

selection and safety-testing of control agents. The genotype or genotypes of the two control agents introduced into South Africa are known to severely damage the target plant, and although both species have attracted local parasitoids, they may be free of cryptic diseases that might otherwise limit success. The agents are well known, abundant, and easily distinguished from other species. These factors would make South Africa a good source of agents. On the other hand, the ability of *T. acaciaelongifoliae* genotypes from South Africa to perform well in Northland remains uncertain, and only the two control agents are available there. Costs of travel to conduct research in South Africa would be high (although in-country costs would be low). Conducting this research in Australia would allow species other than *T. acaciaelongifoliae* and *M. ventralis* to be considered as potential control agents, research sites could be selected that are climatically matched with Northland, and it is likely that the risk to New Zealand native species (such as kōwhai *Sophora microphylla*) resident in Australia could be tested in the field. Travel costs would be relatively low. However, research would be complicated by the relative rarity of species such as *T. acaciaelongifoliae* and *M. ventralis*, the confusion of other related species, and attack by an array of indigenous parasitoids and diseases.

This report recommends systematic identification and evaluation of species, populations and sources of natural enemies that would provide the best likelihood of controlling *A. longifolia* in Northland, and selection of the most promising and safe populations for introduction to New Zealand. The appropriate components of this approach are:

1. Complete a brief economic analysis of biological control as opposed to conventional control methods for the management of *A. longifolia* in New Zealand.
2. Undertake a survey of the plant in New Zealand to check that none of the agents under consideration are already present, and if there are any other organisms here that could be used for biocontrol purposes or that may potentially disrupt a biocontrol programme.
3. From the data collected by Nesar (1985) and van den Berg (in Dennill et al. 1999), and with Australian colleagues, reassess whether there are other potentially effective, host-specific control agents available to attack other life stages of *A. longifolia* in New Zealand. Select 2–3 agents.
4. Determine the areas of Australia within the natural range of *A. longifolia* that most resemble Northland climatically, using the CLIMEX model, and select four appropriate research sites.
5. Obtain samples of *A. longifolia* from New Zealand, South Africa, and 5–10 Australian populations (including sites from which agents were introduced to South Africa), and examine similarity using molecular techniques.
6. Local regulations allowing, determine the compatibility of the selected control agents with New Zealand provenances of *A. longifolia* by growing New Zealand material experimentally at four sites in Australia with climates similar to that of Northland. Compare performance on New Zealand and local provenances for 2 years. Use the design to test the susceptibility of other related plants where possible.
7. Systematically survey the level of attack on legume species in the vicinity of heavily attacked *A. longifolia* in Australia, with special emphasis on *A. melanoxylon*, and especially on New Zealand indigenous species if planted there.
8. Conduct host-range tests on selected control agents in Australia using 5–10 New Zealand legume species.
9. If the programme remains feasible, apply to ERMA for the release of selected agents.
10. Plan formal evaluation of the impact of the agents on *A. longifolia* spread and population dynamics once agents are established.
11. Import, quarantine, rear and release agents in Northland.

12. Monitor for establishment, and begin evaluation.

Growing *A. longifolia* sourced from New Zealand in climatically suitable sites in Australia and South Africa is the most direct method to judge the likely suitability and efficacy of *T. acaciaelongifoliae* and *M. ventralis* in New Zealand. It would require a 2-year lead time to grow plants of appropriate size for this purpose.

The cost of the research listed in points 1–8 is estimated at \$150–200,000 over two years.

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