Prospects for Biological Control of Woolly Nightshade, *Solanum mauritianum* (Solanaceae: Solanoideae)

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1. Summary

1.1 Project and Client

Woolly nightshade (*Solanum mauritianum* Scop.) is widely established in New Zealand and is recognised as a serious environmental weed in northern areas of the country, with scattered infestations further south as far as Manawatu and Nelson. The weed forms dense infestations and spreads rapidly because it produces large numbers of seeds, which birds help to disperse. The cost of control is often prohibitive because, even after areas are cleared, it regenerates from seed for many years. Landcare Research investigated the feasibility of biological control of woolly nightshade for the Auckland, Bay of Plenty, and Northland Regional Councils and Gisborne District Council. Other regions with an interest in the weed include Waikato, Taranaki, Manawatu–Wanganui and Nelson City.

1.2 Objectives

- Record the distribution and weed status of *Solanum mauritianum* in New Zealand.
- Summarise the literature and current information available from biological control of weeds researchers worldwide on the current status of biological control of *S. mauritianum*.
- Assess the likelihood of success of a biological control programme for *S. mauritianum* in New Zealand and review the steps necessary to implement such a programme.
- Propose a realistically costed programme for implementation by the Auckland and Northland Regional Councils, Environment Bay of Plenty, and Gisborne District Council.

1.3 Main Findings

- Woolly nightshade is a serious environmental weed in northern New Zealand, with infestations as far South as Nelson. Its abundant fruits are readily dispersed by birds, so while mechanical and chemical control methods remove plants they do not prevent reinfestation nor invasion of new areas. In principle, biological control offers the best long-term solution to the problem.
- In New Zealand, woolly nightshade, *Solanum mauritianum*, is the only member of the section Brevantherum, while the only other species in its subgenus, also Brevantherum, are three weedy species. This systematic isolation of woolly nightshade within the genus *Solanum* suggests that the prospects of finding agents that will attack woolly nightshade, but not desirable species, may be good.
- A South African programme for biological control of woolly nightshade has progressed to the stage where one agent, *Gargaphia decoris* (Hemiptera: Tingidae), has been released. It is too early to determine the success of this defoliating bug. Several other insects remain candidates, but their host specificity has not yet been determined. The most promising of these are weevils in the genus *Anthonomus*; these feed mainly on flowers and flower buds and, if deemed safe for release, may reduce the problems of invasion and reinfestation by the weed.

- The South African programme was dogged by a tendency for insects to utilise non-target *Solanum* spp., particularly eggplant, in small cage tests. This led to the rejection of several agents, but for other agents including *G. decoris*, several reasons were put forward to argue that these tests were misleading, and the insect posed no significant threat to these plants in the field. Some of these arguments would be equally valid in New Zealand, but others may be less acceptable here; a good example is the argument that eggplant in South Africa is protected by heavy pesticide regimes, but in New Zealand a growing trend towards "organic" crops suggests that this argument would be dismissed.
- Pathogens appear to offer few prospects, either as classical biological control agents or as mycoherbicides.

1.4 Conclusions

- The well-advanced South African programme for biological control of woolly nightshade offers good opportunities to evaluate the likelihood of success of a New Zealand programme. If such a programme proceeded, collaboration with South Africa would save substantial amounts of time, effort and resources. Additional host-specificity testing would be needed for candidate agents and, given the likelihood of expanded host ranges in cage tests, it remains uncertain how ERMA would view this problem and its associated counter-arguments.

1.5 Recommendations

- Survey populations of woolly nightshade and native *Solanum* spp. in different seasons throughout the known range of woolly nightshade in New Zealand to determine which invertebrates and diseases are currently associated with these species in New Zealand (approx. $25,000);
- Monitor progress of the South African programme for biological control of *S. mauritianum* to determine:
    1. whether *Gargaphia decoris* is as specific to woolly nightshade as has been predicted;
    2. whether *G. decoris* inflicts sufficient damage on woolly nightshade in the field to warrant its importation to New Zealand; and
    3. which agents other than *G. decoris* should be investigated for importation to New Zealand.
- Collaborate with the South African researchers to test *G. decoris* and *Anthonomus* against New Zealand native *Solanum* species and Solanaceous crops with current or potential commercial value, other than those tested in South Africa (approx. $25,000).

2. Introduction

Woolly nightshade (*Solanum mauritianum* Scop.) is widely established in New Zealand and is recognised as a serious environmental weed in northern areas of the country, with scattered infestations as far as south Nelson. The weed forms dense infestations and spreads rapidly because it produces large numbers of seeds, which birds help to disperse. The cost of control is often prohibitive because, even after areas are cleared, it regenerates from seed for many years. In June 1999 Landcare Research investigated the feasibility of biological control of woolly nightshade for the Auckland, Bay of Plenty, and Northland Regional Councils and Gisborne District Council. Other regions with an interest in the weed include Waikato, Taranaki, Manawatu–Wanganui and Nelson City.

3. Objectives

- Record the distribution and weed status of *Solanum mauritianum* in New Zealand.
- Summarise the literature and current information available from biological control of weeds researchers worldwide on the current status of biological control of *S. mauritianum*.
- Assess the likelihood of success of a biological control programme for *S. mauritianum* in New Zealand and review the steps necessary to implement such a programme.
- Propose a realistically costed programme for implementation by the Auckland and Northland Regional Councils, Environment Bay of Plenty, and Gisborne District Council.

4. Sources of Information

Information for this report was obtained by searching computer databases (PestCabWeb, Current Contents, UnCover, Agricola) for information on *Solanum mauritianum* and for records of its natural enemies; by cross-referencing known references; by examination of specimens in the Landcare Research herbarium at Lincoln, New Zealand; and from the following people:

Mr Jack Craw, Northland Regional Council, New Zealand;
Dr Jane Fröhlich, Landcare Research, Auckland;
Dr Stephan Halloy, Crop and Food Research, Invermay, New Zealand;
Mr Steve Hix, Auckland Regional Council, New Zealand;
Ms Lynley Hayes, Landcare Research, Lincoln, New Zealand;
Dr Terry Olckers, ARC – Plant Protection Research Institute, Hilton, South Africa;
Mr W.R. (Bill) Sykes, Landcare Research, Lincoln, New Zealand;
Dr Peter Williams, Landcare Research, Nelson, New Zealand.

5. Main Findings

5.1 Distribution and weed status of woolly nightshade in New Zealand

Woolly nightshade is native to Argentina, Brazil, Uruguay and Paraguay, and has naturalised in Africa, Australasia, India and islands of the Atlantic, Indian & Pacific Oceans (Roe 1972). First recorded in New Zealand in 1883 (Allan 1940), it is now widely established and is considered a serious environmental weed in northern areas of the country, being common, and often abundant, North of Taupo. It is common throughout the Auckland region, although some areas, e.g. Great Barrier Island and parts of the Rodney District, are only lightly infested (Auckland Regional Council 1998). Scattered infestations occur throughout most of the remainder of the North Island (Webb *et al*. 1988, Wellington Regional Council 1998). It is a common weed in Wanganui City, with occasional sites in the Horowhenua, Manawatu and Rangitikei (Todd 1999). In Wellington, 12 of 14 infestation sites are now classed as inactive, and eradication of the weed from the last two sites is considered possible (Wellington Regional Council 1998). In the South Island woolly nightshade has a restricted, mostly coastal distribution, being found in Nelson city and parts of north-west Nelson; the Landcare Research herbarium at Lincoln, New Zealand, has specimens from Collingwood, Puponga in Golden Bay, and Nelson city. Its distribution in the northern South Island seems to be constrained by several factors: it is frost-sensitive; it seldom establishes in dense vegetation, most commonly establishes in areas of open gorse but rarely in native vegetation other than occasional occurrences in manuka; and soil conditions may also limit its ability to colonise new areas (P. Williams pers. comm.)

Woolly nightshade grows into a small tree about 10 m tall with a trunk 15–20 cm in diameter. The large, oval leaves are grey–green on top, pale underneath, and with a distinct, felt-like covering of hairs; they have a strong, unpleasant smell when bruised (Webb *et al*. 1988, Roy *et al*. 1998). Woolly nightshade is highly invasive and can form dense thickets that prevent the recruitment and growth of other vegetation. It fruits prolifically, producing clusters of round berries about 1 cm diameter throughout the year. The ripe fruits are yellow (Roy *et al.* 1998) and because they are readily eaten by birds, viable seeds can be distributed widely to establish new populations. The plant grows quickly and can flower and fruit within a year of germination.

Woolly nightshade is suspected to be poisonous to stock (Connor 1977). It is now recognised as a potential hazard to human health, irritating the skin and respiratory tract and sometimes causing nausea when handled (Auckland Regional Council 1998, Hawke's Bay Regional Council 1995, Wellington Regional Council 1998). Its berries are considered poisonous, although probably not as dangerous as those of other *Solanum* species (Sykes 1998).

5.2 Taxonomic status of *Solanum mauritianum* Scop. and its relatives in New Zealand

In any biological control programme it is essential to understand the phylogenetic relationships between the target plant and its relatives, particularly those that are economically or culturally significant (Briese 1996). Woolly nightshade (*Solanum mauritianum* Scop.), occasionally called tobacco weed, kerosene plant, flannel weed or eared nightshade (Hawke's Bay Regional Council 1995, Haley 1998) and better known in South Africa as bugweed (Olckers & Zimmerman 1991), has been known in New Zealand by the synonym *S. auriculatum* (Webb *et al.* 1988). It belongs to the family Solanaceae, and in New Zealand is the sole member of the section Brevantherum, which lies within the subgenus Brevantherum, genus *Solanum* L.. In New Zealand this subgenus comprises *Solanum crispum* Ruíz Lopez et Pavón, *S. diflorum* Vell. and *S. pseudocapsicum* L. (the last two species are both called Jerusalem cherry). The only native species of *Solanum* in New Zealand – indeed, the only native Solanaceae – belong to the subgenus Archaeosolanum; these species are *S. aviculare* Forster f., *S. laciniatum* Aiton, and *S. americanum* Miller, although the last may have been introduced early in New Zealand's human colonisation (Webb *et al.* 1988). None of these 3 species are endemic. Similarly, cultivated *Solanum* spp. like potato and pepino (subgenus Potato) and eggplant (subgenus Lycianthes) are distinct from woolly nightshade both systematically and in habit (Webb *et al.* 1988).

This systematic isolation of woolly nightshade within the genus *Solanum* suggests that the prospects of finding agents that will attack woolly nightshade, but not desirable species, may be good.

Some *Solanum* species are cultivated as crops in New Zealand on a tiny scale, e.g. pepino (*S. muricatum*) and naranjilla (*S. quitoense*). Despite their current small-scale production, these would have to be considered carefully, not just because they are important for a few growers, but because they have not been marketed widely and their potential for further development is high (S. Halloy pers. comm.). A related, although speculative, argument, is that the introduction of *Solanum*-feeding agents may also jeopardise future *Solanum* crops that may be developed from plant species not currently present in New Zealand. However, plants in the genus *Solanum* are a low priority for this development, because many have the potential to become weeds and because there is a risk of accidentally introducing diseases that may affect existing Solanaceous crops like potato (S. Halloy pers. comm.). Both these arguments may be raised during submissions on any application to the Environmental Risk Management Authority (ERMA) for release of a biological control agent for woolly nightshade.

5.3 Current control options

Control of woolly nightshade is problematic. Individual plants and local infestations can be cleared, but reinfestation from seeds means the problem persists and is therefore costly. This lack of an affordable, long-term method of control is one of the major reasons why the Northland Regional Council (NRC) lists woolly nightshade only as a National Surveillance Plant and does not enforce its eradication despite the perception that it is an important weed. Instead, the NRC includes woolly nightshade as one of its six top candidates for biological control and directs resources to research on possible methods of control (J. Craw pers. comm.).

Seedlings can be pulled or dug directly from the ground. For larger plants, the preferred method of control is to cut the plant off about 15 cm from the ground and immediately paint the stump with a solution of herbicide in diesel or water to prevent regrowth. Herbicides recommended for this include amitrole, glyphosate, triclopyr (Grazon), and Tordon Brushkiller; others may also be used (Hawke's Bay Regional Council 1995, Haley 1998). These herbicides can also be sprayed onto the foliage, while Tordon 2G is a granular formulation applied at 30 g m^{-2} within the plant's drip line.

Bulldozing apparently controls infestations when this method is feasible (Auckland Regional Council 1998). Ring-barking is effective for controlling small infestations, particularly in summer when it is more difficult for remnants of the cambium to bridge the gap. However, it is labour-intensive, taking one worker about an hour to ring-bark 30–40 trees (Little 1980). Cutting and stump-painting would be faster and more effective. The importance of good technique when ring-barking is reflected in Auckland Regional Council's recommendations for control: the Auckland Regional Council considers ring-barking or frilling to be effective only if herbicide is applied to the cut area (Auckland Regional Council 1998).

5.4 Potential agents for biological control of woolly nightshade

None of the currently recorded organisms attacking woolly nightshade in New Zealand offer prospects for development as biological controls. Six insects are recorded from the native *S. aviculare* in Dale and Maddison's (1982) checklist. Of these six, *Chrysodeixis eriosoma* is recorded from 21 hosts other than *S. aviculare*, including potato, tomato and tobacco; *Myzus persicae* is associated with a very large range of plants (63 in total), including potato, tomato, tobacco and black nightshade; *Phytomyza syngenesiae* has 25 other plant associations from a range of families including Solanaceae; and *Phthorimaea (=Gnorimoschema) operculella*, the potato tuber moth, is recorded from 9 hosts including potato, tomato, eggplant, tobacco, and black nightshade. Those four insects are adventive or cosmopolitan. Of the remaining two, the native *Sceliodes cordalis* (poroporo stemborer) is recorded only from *S. aviculare*; while *Gellonia* (=*Pseudocoremia*) *dejectaria*, also native, is listed from 10 other hosts, none of which are Solanaceae. Other insects may attack the native New Zealand *Solanum* spp. but either have not been formally recorded, or appear only as attacking other solanaceous plants. Butcher (1984) recorded poroporo (*S. aviculare* and *S. laciniatum* are both called by this common name (Webb *et al.* 1988)) as being the primary host of the caterpillar of *Symmetrischema plaesiosoma* (Turner) (Lepidoptera: Gelechiidae); and he listed the green vegetable bug (*Nezara viridula* (L.), Hemiptera: Pentatomidae), potato cyst nematode (*Globodera* spp., Nematoda: Heteroderidae) and tomato russet mite (*Aculops lycopersici* (Massee), Acari: Eriophyidae) as attacking several solanaceous plants.

Overseas, the first release of a biological control agent for woolly nightshade took place in May 1999 in South Africa (Zimmermann 1999). This release followed an extensive research programme to assess the risk to native and cultivated Solanaceae in South Africa, and was complicated by the discovery that the agent, *Gargaphia decoris*, survived on eggplant and some native *Solanum* species during quarantine evaluations. although it strongly preferred to feed and lay eggs on *S. mauritianum* (Olckers 1999).

Several other insects have been investigated; all, like *G. decoris*, are of South American origin. *Corythaica cyathicollis* (Hemiptera: Tingidae), *Acrolepia xylophragma* (Lepidoptera: Acrolepiidae), *Nealcidion bicristatum* (Coleoptera: Cerambycidae) and five species of *Platyphora* (Coleoptera: Chrysomelidae) were rejected because they were considered not sufficiently host-specific (Olckers 1999). The weevil *Collabismus notulatus* (Coleoptera: Curculionidae) was introduced into quarantine but not cultured; it is thought to gall shoots (Olckers 1999). A leaf-mining flea beetle *Acallepitrix* sp. (Chrysomelidae: Alticinae) may be able to suppress the growth of woolly nightshade plants, and is currently in quarantine in South Africa (T. Olckers pers. comm.). Flowerbud-feeding weevils in the genus *Anthonomus* have great potential because they may reduce the weed's ability to disperse to new areas and to reinfest areas from which the weed has been cleared. *Anthonomus* spp. proved difficult to maintain in culture, and several attempts were necessary in South Africa before *A. santacruzi* was successfully cultured, allowing host-specificity tests to begin (Olckers 1999). These difficulties have now been overcome, although culturing is still labour intensive. Unfortunately the weevils will lay eggs on several native South African *Solanum* spp. and larvae will develop fully on these (T. Olckers pers. comm.). Again, this seems to be an artefact of the small cage experiments, as a survey of insects associated with eggplant in Argentina showed that the weevils did not attack eggplant cultivations despite those crops' proximity to *Anthonomus*-infested woolly nightshade (Olckers 1999). South Africa currently has a cooperative project running in Brazil; this is aimed at determining the weevils' true host ranges. So far, field surveys have failed to detect weevils on any other *Solanum* species (native or cultivated) besides woolly nightshade. Work involving choice tests in open-field situations is expected to provide further evidence that this insect is suitable for release in South Africa (T. Olckers pers. comm.).

Two South American species of stem-boring beetles have also been investigated in South Africa. *Adesmus hemispilus* (Cerambycidae) is considered a low priority and is not currently scheduled for further testing. Adults of the weevil *Conotrachelus squalidus* (Curculionidae) can severely damage woolly nightshade foliage, and this species is considered to be the most promising stem borer; unfortunately, attempts to culture it have so far failed (Olckers 1999).

Issues in host-range testing of Solanum*-feeding insects.*

During South African programmes to investigate biological control of several *Solanum* weeds, including woolly nightshade, many candidate agents were found to utilise potato and/or egg-plant when confined with these plants in small cages. This raised the difficult question of how important this type of test is, given that many of the agents had ample opportunity to attack these and other solanaceous crops under field conditions in their native range, but had seemingly never done so (Olckers & Zimmerman 1991, Olckers *et al.* 1995, Olckers 1998, 1999). The South African researchers rejected some agents largely on the basis of these expanded "physiological host ranges" (Cullen

1990), but argued on several grounds that the release of other agents with relatively broad physiological host ranges, but apparently narrow host preferences under field conditions, should not be curtailed. Some of the arguments are relevant to a programme for woolly nightshade in New Zealand, and are therefore discussed below.

Tests where insects are confined in small cages with no choice of host plant represent a worst-case, and unrealistic, situation. Their main use is to show that the insect will not attack an alternative host; in short, that it will starve and die rather than feed on the non-target plant. If this is indeed the result, then it provides the strongest possible evidence that the insect poses negligible risk to that plant. Unfortunately, in these tests some insects will attack plants they would otherwise avoid, leaving the researcher with the difficult task of assessing the significance of this result. Choice tests confine the insect with the target plant and one or more alternative plants; these tests supposedly measure the insect's preference for the target over the non-target plant (Heard 1997). However, they can be misleading because in small cages odours from the host plant can encourage the insect to attack the non-target plant (Thiery & Visser 1986, 1987); moreover, they may place the target plant in close proximity to a plant that would not normally be found near the target plant. Consequently, choice tests, like no-choice tests, are biased in favour of demonstrating that an insect will attack an alternative host plant. They provide a good assurance of the agent's safety if the alternative host is not attacked, but should the agent attack the alternative host it is difficult to assess the relevance of such a result.

In South Africa, egg-plant crops are heavily sprayed with pesticides and grown in rotation with other crops (Olckers & Zimmerman 1991, Olckers & Hulley 1995, Olckers *et al.* 1995). These practices would kill agents that might transfer from woolly nightshade, so there appears to be little risk of these agents causing significant damage. However, increasing demand for organically grown produce in New Zealand may weaken this argument.

In South Africa most egg-plant crops are distant from woolly nightshade infestations, so the probability that woolly nightshade agents would colonise ephemeral crops is low. The probability of infestation of egg-plant crops may also be low in New Zealand, although for a different reason, *viz.* most egg-plant crops are grown in glasshouses, where the risk of accidental infestation may be lower than in field cultivations.

Many native insects fed on native *Solanum* spp. in South Africa, but few attacked *S. mauritianum* and none caused significant damage despite the weed's abundance. This was used to support the release of *G. decoris* because, it was argued, such a result provides some justification for concluding that the reverse would also apply, *viz.* that imported agents are unlikely to exploit and inflict serious damage on native *Solanum* spp. (Olckers & Hulley 1995, Olckers 1999). The same reasoning might also be used to argue that agents introduced to New Zealand to control woolly nightshade are unlikely to damage the three New Zealand native *Solanum* spp. The simplest way to determine this would be to test the agents directly on the three native species, either in New Zealand or overseas.

Pathogens.
Fungi appear to offer few prospects as either classical biological control agents or as mycoherbicides. Overseas, few fungi have been recorded from woolly nightshade and none are specific to the weed (Johnston 1990). In New Zealand, several fungi utilise woolly nightshade, but only two are recorded in the literature: *Erysiphe orontii*, with 40 hosts, and the leaf-spotting fungus *Mycovellosiella brachycarpa* (McKenzie 1999). The latter is formally recorded only from woolly nightshade but, like all other fungi so far found on this weed, is not specific to it; it is difficult to culture so has little potential as a mycoherbicide (Johnston 1990). More extensive surveys overseas might disclose other, currently unrecorded pathogens of woolly nightshade, but at present resources are probably better utilised by collaborating with the South African work on insects.

5.5 Prospects for achieving successful control of woolly nightshade through biological control

The success of the beetle *Leptinotarsa texana* (Coleoptera: Chrysomelidae) in the South African programme against *S. elaeagnifolium* (Hoffmann *et al.* 1998) has raised hopes for similar success against *S. mauritianum* (Olckers 1999). Several insects have characteristics that would contribute to a successful New Zealand programme, but only one, *G. decoris*, has been investigated thoroughly. This insect has been released in South Africa, but would need further investigation in New Zealand. The other candidate agents would complement *G. decoris* well, by attacking other parts of the plant; in particular, *Anthonomus* spp. may be able to reduce fruit production and therefore lower the weed's invasive capabilities. Leaf-mining and stem-boring insects might also reduce the plant’s vigour and therefore, indirectly reduce fruit production. This would probably be their main contribution to effective control, as it is unlikely that they would inflict enough damage to kill plants. However, these agents still need to be extensively tested to determine the risk they pose to native and cultivated *Solanum* spp.

6. Conclusions

New Zealand has an excellent opportunity to capitalise on the South African programme against woolly nightshade. Several promising agents have been identified, and one has already been released in South Africa, offering the opportunity to evaluate the validity of the arguments used to justify its release. New Zealand could collaborate with the South African researchers to hasten a similar programme for woolly nightshade in this country. Additional host-specificity testing would be needed to determine the risk to New Zealand native *Solanum* spp. and crops not tested in South Africa (e.g., pepino, naranjilla). Given the likelihood that any agent proposed for woolly nightshade control could be induced to feed on a *Solanum* crop or native *Solanum* species in cage tests, it remains uncertain how ERMA would interpret this problem and its associated counter-arguments.

7. Recommendations

- Survey populations of woolly nightshade and poroporo in different seasons throughout the known range of woolly nightshade in New Zealand to determine which invertebrates and diseases are currently associated with these species in New Zealand (approx. $25,000);
- Monitor progress of the South African programme for biological control of *S. mauritianum* to determine:
    1. whether *Gargaphia decoris* is as specific to woolly nightshade as has been predicted;
    2. whether *G. decoris* inflicts sufficient damage on woolly nightshade in the field to warrant its importation to New Zealand; and
    3. which agents other than *G. decoris* should be investigated for importation to New Zealand.
- Collaborate with the South African researchers to test *G. decoris* and *Anthonomus* against New Zealand native *Solanum* species and Solanaceous crops with current or potential commercial value, other than those tested in South Africa (approx. $25,000).

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