Release of *Uromyces heliotropii* in Australia: A Key Agent in the Integrated Pest Management System for Common Heliotrope

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Common heliotrope, *Heliotropium europaeum* (Boraginaceae) is a highly competitive, poisonous, summer-growing, annual weed from Mediterranean Europe and North Africa. It causes over $46 M p.a. damage to Australian agriculture, and displaces native plant species. It sets seed within weeks after germination and has large soil seed banks in Australia. Thus, an integrated pest management (IPM) program is being developed for common heliotrope, with biological control as the base strategy, using agents that act early in the season. The most promising biological control agent species for common heliotrope is a rust fungus, *Uromyces heliotropii*. A new protocol for selection of test species for host-specificity testing ("the relatedness testing procedure") was developed for *U. heliotropii*. This protocol emphasized selection of species based on their relatedness to common heliotrope, attack by other *Uromyces* spp., and affinities with Australian flora. Isolate UH139 from Turkey of *U. heliotropii* was released on 2 farms in summer 1991 after 6 yrs of testing. The mycological ecology and epidemiology of *U. heliotropii* is being evaluated. Adverse weather conditions post-release at a Western Australian site limited disease development. However, better conditions at a New South Wales site allowed for rapid disease development, and inoculated plants were killed within 3 generations of the rust. Spread of the fungus to marked plants at various distances from inoculated plants was also observed. Non-target Boraginaceae are also being examined in the field. Establishment is very likely, and there is excellent potential for early season, significant damage to common heliotrope by *U. heliotropii*. Other agents are being studied to complement *U. heliotropii*. To maximize scientific and political success, it is essential to build biological control of weeds research and implementation IPM programs around a sound scientific rationale and with maximum interaction with affected groups.

Introduction

*Heliotropium europaeum* L. (Boraginaceae), common heliotrope, has been the subject of a biological control program in Australia since 1971, when the Australian Weeds Committee (AWC) rated it as a priority weed. Historical aspects and the economic, environmental and scientific rationale for this program were discussed by Delfosse and Cullen (1981) and Delfosse (1985). In brief, common heliotrope is a major summer-growing, annual Mediterranean weed. It is extremely toxic to grazing livestock, competes vigorously with crops and pasture, and displaces native species. It causes > $46 M damage yearly to Australian agriculture, and

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displaces native plant species. Chemical, cultural, and biological control strategies have been investigated separately to manage common heliotrope.

The key point in the phenology of the weed is that it sets seed a few weeks after germination, so any strategy, including biological control, must act quickly to be ineffective. Thus, we are developing an integrated pest management (IPM) program for common heliotrope, with biological control as the base strategy.

The AWC was not the first group that rated common heliotrope highly as a weed to be targeted for biological control. In fact, in the 1950s CSIRO conducted surveys in Mediterranean Europe and North Africa to determine if there were any natural enemies of common heliotrope which had potential as biological control agent species for the weed.

Of the herbivores collected from Heliotropium spp., only 6 species were rated as having the maximum potential as biological control agents (Table 1). Seven others were considered to attack an important phenostage, and should be investigated. Most of the 122 species of arthropods and diseases found associated with the plant were discounted because they are known plant pests or insufficient information was available about their host range (Delfosse 1985, and unpublished data).

A flea beetle, Longitarsus albineus (Foudras) (Coleoptera: Chrysomelidae), was rated as having good potential as a biological control agent for common heliotrope. This species was released in Australia several times since 1979 (Delfosse 1985), but has not yet become established widely and has no effect on the weed. Reasons for this apparent lack of establishment are not yet known.

This paper reports the first releases in Australia of a rust fungus, Uromyces heliotropii Sredinski (Uredinales). We also discuss the recent field discovery of L. albineus, and propose re-examining some of the other species found during the early surveys of common heliotrope in North Africa. Finally we discuss the experimental design for field evaluation for evaluating releases of multiple agents against a target weed, the need to develop IPM systems for weeds around establishment and conservation of effective natural enemies, and implementation of IPM programs based on a high level of co-operation among researchers, States, landowners and other affected groups.

**First Australian Releases of U. heliotropii**

*U. heliotropii* is a macrocyclic, autoecious rust fungus. It attacks common heliotrope soon after it germinates, and can kill plants directly. Thus, it is the most promising of all the known potential agent species (Table 1) for common heliotrope (Delfosse 1985, Hasan 1985). Priority was thus given to host-specificity-testing of *U. heliotropii*.

**Life Cycle**

From spring to early summer, teliospores germinate on young seedlings, forming spermatonia, and then yellow aecidia and aecidiospores. Aecidia appear in groups, forming concentric rings, mostly on the lower surfaces of leaves. Aecidia contain yellow aecidiospores, which infect leaves and stems, giving rise to successive generations of dark brown uredinia. Uredinia rupture the epidermis, releasing urediniospores, which are responsible for the further dispersal of *U. heliotropii*.

Infection also originates early in the season from urediniospores produced from uredinia which overwintered on the previous season's dead plants.

In summer, several generations of urediniospores develop, with infection readily transferred to other *H. europaeum plants*. Uredinia are borne in yellowish spots on both leaf surfaces, but mostly on the upper surface. They are often large and abundant, and cover entire leaf surfaces, giving rise to large quantities of powdery, brown urediniospores. In severe attacks, the whole leaf surface, and even the whole plant, looks brown.

From late summer to autumn, black telia appear among uredinia on leaves and stems. Telia contain dark brown to black teliospores. Teliospores are more abundant toward the end of summer or in autumn on the fully-grown plants. Mature teliospores can germinate immediately after production.

From autumn to early spring, teliospores and urediniospores overwinter on dead plants.
Table 1. Known and potential biological control agent species for common heliotrope, *Heliotropium europaeum*.

<table>
<thead>
<tr>
<th>Species</th>
<th>Plant Part Attacked</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Known agent species</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Longitarsus albineus</em> (Foudras)</td>
<td>Adults create shot-holes in leaves; larvae feed on diffuse roots</td>
<td>Established, but at very low levels which do not damage common heliotrope</td>
</tr>
<tr>
<td>(Coleoptera: Chrysomelidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Uromyces heliotropii</em> Sredinski</td>
<td>Leaves and stems</td>
<td>Released in 1991 and 1992. Likely established, but no effect on common heliotrope yet. Further releases likely.</td>
</tr>
<tr>
<td>(Uredinales) (Isolate UH139 from Turkey)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pachycerus cordiger</em> Germ.</td>
<td>Adults - leaves; larvae - roots</td>
<td>Application for field release pending</td>
</tr>
<tr>
<td>(Coleoptera: Chrysomelidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ethmia distigmatella</em> Erschoff</td>
<td>Cymes</td>
<td>Imported for host-specificity testing</td>
</tr>
<tr>
<td>(Lepidoptera: Ethmiidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cercospora heliotropii-bocconii</em></td>
<td>Leaves (and possibly seeds)</td>
<td>Host-specificity testing currently underway in France</td>
</tr>
<tr>
<td>Scalia (Hyphomycetes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Utethesia pulchella</em> (L.)</td>
<td>Leaves</td>
<td>No work currently underway</td>
</tr>
<tr>
<td>(Lepidoptera: Arctiidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Potential agent species</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unspecified gall-forming mite</td>
<td>Growing points</td>
<td>Recorded by Wilson (1951)</td>
</tr>
<tr>
<td>(Acari: Eriophyidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unspecified gall-forming fly</td>
<td>Cyme</td>
<td>Recorded by Wilson (1951) from Kenya</td>
</tr>
<tr>
<td>(Diptera: Cecidomyiidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Austrogallia sinuata</em> (M.R.)</td>
<td>Leaves</td>
<td>Recorded by Wilson (1951) from Iran</td>
</tr>
<tr>
<td>(Hemiptera: Cicadellidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Austrogallia sp.</em></td>
<td>Leaves</td>
<td>Recorded by Wapshere (1975) from Algeria and Tunisia</td>
</tr>
<tr>
<td>(Hemiptera: Cicadellidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Atmoscelis signaticornis</em> Reut.</td>
<td>Leaves</td>
<td>Recorded by Wilson (1951) from Kenya</td>
</tr>
<tr>
<td>(Hemiptera: Miridae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Neoliturus opacipennis</em> (Leth)</td>
<td>Leaves</td>
<td>Recorded by Wilson (1951) from Kenya</td>
</tr>
<tr>
<td>(Hemiptera: Cicadellidae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Polymemrs (= Poeciloscytus) sp.</em></td>
<td>Leaves</td>
<td>Recorded by Wilson (1951) from Kenya</td>
</tr>
<tr>
<td>(Hemiptera: Miridae)</td>
<td></td>
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</tr>
</tbody>
</table>

**Testing and Importation**

A 6-yr host-specificity testing program for *U. heliotropii* was completed in late 1988 (Hasan *et al.* 1992). Isolate UH139 from Turkey, which was found to be virulent against Australian common heliotrope, was used in the testing. Following testing, the rust was imported to quarantine in Canberra in March 1990. This was the first time that Australian quarantine and wildlife officials allowed importation of a fungus for biological control before permission for its field release had been given. This significant event was possible.
because of the sophisticated features of the new CSIRO High Security Quarantine Building in Canberra, combined with experienced staff and an approved standard operating procedure, and an open, cooperative relationship between regulatory and research personnel.

The rust was mass-cultured under strict quarantine conditions until January 1991. During the mass-culture period, the fungus was checked frequently for hyperparasites; none were found. Quarantine and wildlife officials accepted, following peer review, a risk assessment for the program prepared by CSIRO, and approval for field release of U. heliotropii was given. Spores were stored at 0°C until used for further inoculations or field release.

The First Australian Field Releases

Experimental conditions. U. heliotropii was first released on farms near Jugiong, New South Wales (18 January 1991) and Gnowangerup, Western Australia (22 January 1991). Cooperating landowners and local agricultural officials were invited to these initial releases. At each site, data on plant size, number of leaves, cyme and seed production, and disease development were taken before release and every 7- to 14-d thereafter until the first frost. Similar data were taken from 10 sentinel plants, placed at points up to 100 m away from the point of release. A weather station was set up at both sites at the end of the season. Parameters recorded include wind speed and direction, leaf wetness, temperature, and RH.

Two methods (the brush method and the spore suspension method) were used during field inoculation, which occurred at about 6:00 PM on the day of inoculation. A high humidity chamber was made by placing a plastic bag on a metal frame, which was placed over the inoculated plant. The base of the frame was inserted into the soil at the base of the plant to a depth of ca. 1 cm. Distilled water was misted into this chamber through a hole cut for this purpose. The hole was then sealed with tape. The humid chamber was removed at 6:00 AM the following morning, and temperature, dew and other weather conditions were noted.

The brush method. Distilled water was first lightly misted onto plants. About 8 mg of U. heliotropii urediniospores were then applied to each of 6 plants (a camel hair brush was dipped into a vial containing the dried spores, which were brushed onto several leaves on each plant), and the plant was covered with the high humidity chamber. This method was used at Jugiong only.

The spore suspension method. Forty mg of U. heliotropii urediniospores were added to 100 ml of distilled water in an atomizer. Plants were drenched with the suspension and covered with a high humidity chamber as for the brush method. This method was used at both sites.

Jugiong. Conditions were very favorable for infection immediately following release (mild temperatures and overnight dews), and establishment seemed likely. The mycological ecology of U. heliotropii was followed in great detail on the marked plants (Delfosse, unpublished data). By mid-February, the rust had moved naturally to new plants at Jugiong. By mid-March (~6 wks, or 3 rust generations) all inoculated plants were killed, and attack on adjacent plants was heavy (several sorus leaf, with occasional entire leaves covered). By the time the plants were killed by frost in April, all inoculated plants were killed, and spread of U. heliotropii had been recorded from all sentinel plants, up to 100 m from the point of inoculation.

Prospects for establishment of U. heliotropii at the Jugiong site are thus excellent. The site will be monitored for several years to determine establishment and to evaluate subsequent disease development and effects on the target weed. Other native and introduced Boraginaceae have been located in the release area, and these will be monitored during the study to determine any non-target effects.

Gnowangerup. Unlike the previous season, the only common heliotrope plants which germinated at this site were on a fire break. However, plant condition was good, and it was felt that, given favorable conditions following inoculation, the fungus should become established. Unfortunately, conditions immediately following inoculation were far from favorable at the Gnowangerup site: the weather was hot and dry, and there were only a few light overnight dews. Even given this set of
conditions, some natural spread of *U. heliotropii* occurred at the Gnowangerup site, albeit much less than at the Jugiong site. Therefore, it is likely that further releases will be necessary next season at Gnowangerup. Effect on common heliotrope and on non-target Boraginaceae will be evaluated for several years at the site.

**Other sites.** Additional release sites for *U. heliotropii* will be established in South Australia, Victoria and New South Wales (Table 2). Establishment, impact on the target weed, and monitoring of non-target Boraginaceae will be evaluated as for other sites.

**L. albineus: Now You See It, Now You Don't**

The first agent for common heliotrope released in Australia is a flea beetle, *L. albineus* (Delfosse and Cullan 1981). It is the most common and widespread of the natural enemies found on common heliotrope in its native range. Adults of this beetle feed on leaves of common heliotrope, creating small “shot holes;” the larvae feed on the rootlets of the weed, and cause more damage than do adults.

The first field release of this species was made on 28 December 1979 near Jugiong, New South Wales. Recoveries were made at the release site the following season, indicating that *L. albineus* successfully overwintered in the field. However, a 3-year drought began in 1980 during which very little common heliotrope germinated in the field, and it is likely that the beetle died out for lack of food.

Further releases were made in 1981 near Jugiong, Urana and Corowa, New South Wales. Again small numbers were found the following season, and it appeared that the beetle would become established. Unfortunately, the following season was also very dry, producing little common heliotrope year, and there were no more recoveries at release sites.

Subsequent releases of *L. albineus* have been made at sites in New South Wales and Victoria, but only very low numbers were recovered the season following release. The reasons for lack of rapid establishment by this species are unknown.

However, monitoring has continued at all sites since 1979, as part of the study on the ecology and demography of common heliotrope, and because it is not unusual for an agent to “disappear” in the field after release for, in some cases, several years. This monitoring has paid off: in January 1992, 12 yrs after the first release, *L. albineus* was again recovered in the field at Jugiong. Its status is being evaluated.

**Other Biological Control Agents for Common Heliotrope**

We rate the following three agents highly for their potential to contribute to management of common heliotrope (Table 1). The insects become active too late (i.e., >6 wks) into the season to contribute to seedling management, but may be useful in reducing biotic potential of plants that escape attack of the fungi.

*The Common Heliotrope Weevil, Pachycerus cordiger*

Testing of the second insect biological control agent for common heliotrope, a weevil (*Pachycerus cordiger*), has been completed. It was imported to quarantine in Canberra in February 1987 and is being mass-reared. An application for release has been prepared.

Adults of *P. cordiger* feed on leaves of common heliotrope, creating large, oval, holes. Larvae (grubs) feed in the crown of the plant, and, like the flea beetle, cause more damage to common heliotrope than do adults.

*The Common Heliotrope Bud-feeding Moth, Ethmia distigmatella*

Permission has been received to import *E. distigmatella* to quarantine for host-specificity testing. Adults of the moth do not feed, but larvae eat developing seeds, and could thus be important in the control strategy.

Three collections of this species were made in Turkey (1988-9), but insufficient material was found to develop a rearing colony. A new colony was collected in Turkey in 1990, and sent to quarantine in Canberra. For the first time, a successful rearing procedure has been developed. If the colony can be continued, which appears likely, host-specificity testing will
begin in quarantine in Canberra. This is expected to take about 3 yrs.

*The Common Heliotrope Leaf-blotch Fungus, Cercospora heliotropii-bocconi*

Another very-promising potential agent is *C. heliotropii-bocconi*, which causes a leaf-blotch disease on common heliotrope. Host-specificity testing for this species began at the CSIRO Biological Control Unit in Montpellier, France, in late 1988, and is expected to take 3 yrs. The relatedness testing procedure (Delfosse, unpublished data) is being used.

Results to date on the critical test plant species (other *Heliotropium* spp.) indicate that *C. heliotropii-bocconi* may have a similar host range to *U. heliotropii*; i.e., restricted to species in the same subgenus. It is thus likely that this species will be sufficiently specific for introduction.

A recent discovery of major potential significance is that this fungus appears to kill seeds produced on the plant and after they drop to the soil (Hasan, unpublished data). If this is confirmed, *C. heliotropii-bocconi* is the only agent species known for common heliotrope which kills dropped seeds. This could be very important in the IPM program.

*Integrated Management of Common Heliotrope*

Very few annual plants are targets for biological control (Julien 1992). This is partly due to what we believe is a misconception about the likelihood of success of such programs. It is reported that the chance of successful biological control of a perennial weed, particularly if it is an inbreeding species or apomict, is much higher than for sexually outbreeding species (Burdon

However, this conclusion is misleading. Relatively little scientific (or funding), effort has been directed toward biological control of annual weeds, and yet there have still been some significant successes (e.g., Tribulus cistoides in Hawaii, T. terrestris in parts of the United States, etc.; Julien 1992). There do not appear to be any valid ecological reasons why an annual or biennial plant should be more difficult than a perennial or apomictic species to manage with natural enemies as part of an IPM system; each plant type presents different challenges.

When CSIRO began the common heliotrope and Paterson’s curse (Echium plantagineum L.; Boraginaceae) programs in 1979, 2 critical decisions were made, based on visioning how these programs could best be conducted to maximize the chances of success and of contributing to basic biological control theory.

First, the ability to locate safe natural enemies for the weeds, particularly those effective early in the season and at low plant densities, will depend on a high level of knowledge of the ecology of the species. A detailed examination of their ecology in the native ranges is critical to this understanding. Factors such as phenology, demography, seed aspects (production, soil seed banks, seed rain, longevity, etc.), and natural enemies will be emphasized.

Second, this work will be done in parallel in Australia and Europe, indicating key areas for concentrating the effort for biological control, and contributing useful information to biological control theory of annual and biennial weeds and the interactions between herbivores and their plant hosts. Some of these key areas are discussed below.

Seed Factors and Key Phenostages

H. europaeum has high seed production and large seed banks in Australia (~100,000 seeds/m² at some sites; Delfosse, unpublished data). Seeds in soil can survive for many years. Seeds germinate in spring to summer, and plants die after the first frost in autumn.

Common heliotrope starts to set seed after a few weeks, when plants are just a few cm tall (Delfosse and Cullen 1981). Killing the key phenostages (seedlings and very young plants) very early in the season, thus reducing eventual seed production, is therefore the basic strategy for this program.

It appears that the insect agents take at least 6 wks to build up each season, by which time the plant has already set significant amounts of seed. The 2 pathogens (U. heliotropii and C. heliotropii-bocconi) develop earlier in the season and have a much higher biotic potential and rate of spread, so offer the best possibilities for killing plants before seed set.

Ecoclimatic Matching

Ecoclimatically-similar European and North African areas of common heliotrope distribution were given priority for searching for natural enemies. Due to political challenges in searching parts of North Africa, and particularly to funding restrictions, most of the recent work has concentrated in Mediterranean Europe.

However, a new IPM-based initiative has recently been funded by the Australian Meat and Livestock Research and Development Corporation (AMLRDC). This initiative supports a new technical assistant on this project at the CSIRO Biological Control Unit in Montpellier, France. Thus, it now appears that North African areas will be able to be searched for some of the potential species found in the early work (Table 1).

Field Evaluation of Single- vs. Multiple-Species Releases of Common Heliotrope Agents

The pattern for release and evaluation of biological control agents for common heliotrope is given in Table 2. Evaluation of releases following this pattern should allow determination of whether single- or multiple-species releases work better for establishment of agents for this annual weed.

Technology Transfer

Key to this IPM program is early and meaningful involvement with partners, resulting in efficient technology transfer (i.e., delivery of agents).

This program was, in fact, established on this partnership principle. Since 1979 CSIRO
brokered the involvement of many groups. AMLRDC provides funding. State Departments of Agriculture (or equivalent) help plan, release and evaluate agents. Local (Shire Council) officials enthusiastically identify “lead farmers” in their areas, and help negotiate long-term use of the land. Landowners enthusiastically provide the sites (and any fencing, watering, etc., needed), and expertise in farming systems to ensure that the program fits in with farm management. (This is particularly important because pasture management to conserve natural enemies, and to help reduce seeding by common heliotrope, is essential to the program.) Environmental groups (and others) help identify potential non-target Boraginaceae, and support use of relatively host-specific natural enemies. CSIRO provides research expertise, quarantine and mass-rearing facilities, and biological control agents.

Technology transfer in this program is thus a true partnership. The evaluation phase of this program should continue for several years to capture all of the benefits of the partnership.

Expectations for IPM of Common Heliotrope

Despite the disappointing outcome with *L. albimeus*, prospects for successful IPM of common heliotrope are high for 3 main reasons. First, the natural enemies (particularly the fungi) attack all phenostages of the weed, are very damaging, and have the capacity to build up large numbers and spread quickly. Handled properly, they can provide the necessary sustainable basis for this IPM effort.

Second, it is recognized widely that this IPM approach offers the only economically and environmentally feasible way to manage common heliotrope. Support for this program is strong in the research, farming and environmental communities.

Third, long-term funding support from the AMLRDC is indicated. They accept that it will take several years more basic research before the impact of the agent species can be determined, and support the technology transfer and partnership facilitation by CSIRO.

In conclusion, the scientific success of learning more about this agent:plant system must continue to be matched by political success in involving appropriate partners in developing and transferring the program.

Acknowledgments

The generous assistance by landowners and managers at research sites—all working farms—and officers of local Shire Councils, State Departments of Agriculture and similar bodies is gratefully acknowledged. This program is built on a foundation of building partnerships with the States, and would fail without strong local support. This program could not be conducted without substantial financial and philosophical support from the Australian Meat and Livestock Research and Development Corporation.

References


