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## The Biological Control Program Against Gorse in New Zealand

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### Abstract

Gorse (*Ulex europaeus* L.: Fabaceae) has been a serious weed in New Zealand for over 100 yr, and continues to invade pastoral land, forest plantations, and vulnerable natural habitats. It has beneficial uses, but these are far outweighed by the costs. Gorse was once an important hedge plant, and until 1982, seed-feeding insects were the only biological controls considered appropriate. *Exapion ulicis* Forst. was released in 1931, and destroys about 35% of the annual seed crop. Six control agents have been introduced since 1988. *Cydia succedana* (Dennis and Schiffermüller) was released in 1992. Assessment at 1 site shows that the 2 seed-feeding insects can destroy about 90% of the annual seed crop. Gorse spider mite (*Tetranychus lintearius* Dufour) was introduced from several sources in Europe in 1989 and 1990, and established widely. Mite outbreaks severely damage plants, and reduce flowering, but populations large enough to kill mature gorse plants over wide areas cannot be sustained, probably because of predation. The gorse thrips, *Sericothrips staphylinus* Haliday, was introduced in 1990. It has spread only slowly, but significantly damaged gorse foliage in experimental studies. The foliage-feeding moths *Agonopterix ulicetella* (Stainton) and *Pempelia genistella* (Duponchel) have been released. Establishment is not yet certain. The scythridid moth, *Scythris grandipennis* (Haworth), has also been released, but it did not establish. No further releases are planned. Development of a bioherbicide augments the classical approach to biological control of gorse. The paper discusses the impact of control agents, and the future of the research. The New Zealand program has provided information and control agents to similar programs in Hawaii, Oregon and California, Chile, and Australia.

**Keywords:** Gorse, *Ulex europaeus*, New Zealand, seed

### Introduction

Gorse (*Ulex europaeus* L.: Fabaceae) is a spiny shrub that can form fast growing impenetrable thickets up to 4 m tall in New Zealand. Even-aged stands can live up to 29 yr (Lee *et al.* 1986). Plants can produce 34,000 seeds per m<sup>2</sup> per annum (unpublished data), and the seeds can be long-lived in the soil (Hill *et al.* 1999). Gorse is highly invasive. Blaschke *et al.* (1981) recorded it in varying densities on 700,000 ha of New Zealand. This is approximately 5% of the land area not occupied by indigenous forest, or alpine or sub-alpine vegetation. It covers land suitable for agriculture. It shades out tree seedlings in new plantation forests, and then reduces growth of surviving trees, and invades vulnerable natural habitats. Gorse is combustible, and increases the fire risk in forests and peri-urban areas.

Gorse was introduced to New Zealand as a hedge plant before 1838, and ribbons of

potential weeds were soon established across the landscape. Gorse spread quickly, and by 1900 it was declared a weed by Act of Parliament. Nevertheless, live gorse fences continued to play a crucial role in New Zealand's agricultural development for another 50 yr, until most were replaced by posts and wire. This created the paradox of an acknowledged weed that was also of significant agricultural value, and conflicting attitudes about gorse influenced the direction of biological control research until 1988. The extensive literature concerning the biology, ecology, economics, and control of gorse has been reviewed comprehensively by MacCarter and Gaynor (1980), Gaynor and MacCarter (1981), and more recently by Richardson and Hill (1998).

The first attempt to control gorse biologically was one of the earliest undertaken worldwide. The value of gorse as an inexpensive live fence, and shelter plant was taken into account, and the initial search for agents in Europe was restricted to those insects that damaged flower buds, flowers, and pods (Miller 1970). Davies (1928) recorded that 92% of the pods that he examined in England were infested with gorse seed weevil *Apion ulicis* Forster, and recommended this species as a control agent. The weevil was duly imported into New Zealand in 1928, and was widely released from 1931 to 1947. Soon the proportion of pods infested in spring approached the levels observed in England by Davies, and Miller (1970) intimated that successful control was expected. However, the high levels of pod infestation recorded were misleading. Gorse can form seeds in both spring and autumn, while *E. ulicis* is only active in spring. Later studies have revealed that where the bulk of annual seed production is in autumn, infestation of the small number of pods formed in spring often exceeds 90%. However, where most seed develops in spring, production swamps the weevil, and the rate of seed destruction is lower (Hill *et al.* 1991a). Cowley (1983) found that although infestation of pods in spring was high in the area she studied, seed weevil only reduced the annual seed crop by about 35%. Markin and Yoshioka (1996) observed that feeding by adult *E. ulicis* caused significant damage to gorse foliage.

Chater (1931) noted at least 5 insects that fed on reproductive structures on gorse, but no further agents were introduced at that time, possibly because of the apparent success of the weevil. Later, the use of phenoxy herbicides, and management by fire were considered the best solutions to the gorse problem (Gaynor and MacCarter 1981). Zwölfer (1962) completed a comprehensive review of the phytophagous fauna of gorse in Europe, and evaluated the potential of each one as a biological control agent (Schroeder and Zwölfer 1970). However, it was not until 1978 that biological control was considered once more. MacCarter and Gaynor (1980) reviewed all of the information available about gorse in New Zealand, the insects that attack it there, and the biological control options available in Europe. Hill (1982) studied some of the relationships between gorse and its fauna in Europe, and in collaboration with CABI Bioscience, host-range testing of several agents in Europe began in 1980. The program was stalled in 1982 by a public debate about whether the potential benefits that would accrue to New Zealand agriculture from biological control of gorse outweighed the potential costs. Apart from its (declining) value as a hedge, gorse was seen as a source of pollen for bees, and a forage plant for the burgeoning goat-farming industry (Richardson and Hill 1998). Most importantly, some ecologists and environmentalists feared that biological control would have an adverse effect on the role of gorse as a nurse-plant for the restoration of native vegetation on much abandoned agricultural land (Hill and Sandrey 1986, Wilson 1994). After extensive public consultation, and independent assessment of the assembled information (Hill 1987, Hill 1990),

these issues were resolved. Approval to introduce the first foliage-feeding control agent was granted in 1989. Since then, 6 insects have been introduced to New Zealand to attack gorse (Harman *et al.* 1996).

### Introduction of biological control agents, 1989-1995

#### *Tetranychus lintearius* Dufour, gorse spider mite

A population of gorse spider mite, *Tetranychus lintearius* Dufour, from England was introduced to New Zealand in 1989 (Hill *et al.* 1989), but failed to establish in the warmest and wettest regions (Hill *et al.* 1991b). A temperature-driven population model gave excellent prediction of mite phenology, and indicated that mites would complete 6 generations in the north of New Zealand, and 4-5 in the south. However, the model suggested that temperature alone was not the determinant of establishment success (Hayes *et al.* 1996, 1999). Millar (1993) showed that the reproductive performance of strains varied under artificial rain. Further populations were imported from NW Spain and Portugal and released. Comparative trials in a region where the mites from England originally failed to establish indicated that the new populations performed better (Hill *et al.* 1993). *Gorse spider mite* is now established throughout New Zealand.

#### *Sericothrips staphylinus* Haliday, gorse thrips

The gorse thrips was released in New Zealand in 1990 and is widely established (Harman *et al.* 1996). The evaluation of *S. staphylinus*, its introduction to New Zealand and Hawai'i, and its establishment have been summarized by Hill *et al.* (2000). It was released in Hawai'i in 1991, established, and is spreading (Markin *et al.* 1996, Hill *et al.* 1999). Although established at many sites throughout New Zealand, gorse thrips has not spread rapidly, probably because winged individuals are relatively rare (Hill *et al.* 1999). Thrips extract mesophyll, causing small white lesions on green shoots.

#### *Agonopterix ulicetella* (Stainton)

Larvae of this oecophorid moth feed on new gorse growth in spring (Hill *et al.* 1995). The moth has been released repeatedly in New Zealand since 1990 (Harman *et al.* 1996) but has established only sporadically and at low densities. *A. ulicetella* was released in large numbers in Hawai'i from 1988-1990, and despite heavy pupal parasitism, has established and spread throughout the gorse infestations. The extensive damage to new growth each spring is conspicuous (Markin *et al.* 1996), but its long-term impact on gorse is uncertain.

#### *Scythris grandipennis* (Haworth)

*S. grandipennis* (Scythrididae) is a univoltine moth, with solitary larvae that are 1.5 cm long when fully grown. These form complex, 2 cm-diameter white webs, often at the junction of the stems, and larvae forage from these webs to feed on mature gorse foliage from autumn to spring. *S. grandipennis* proved to be a very difficult insect to rear in the laboratory. Nevertheless, it was possible to complete adequate host-range tests (A.H. Gourlay and S.V. Fowler, unpublished data) that demonstrated a high degree of host-specificity. Adults laid eggs only spasmodically, and it was not possible to build the numbers of this moth in the laboratory. One hundred pupae in webs were released at 1 site in Canterbury in spring 1993 (Harman *et al.* 1996). One adult was seen shortly after that, but larvae have never been observed at the site. This species has not established in New Zealand.

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### ***Pempelia genistella* (Duponchel)**

Like *S. grandipennis*, *Pempelia genistella* is univoltine, and larvae are most commonly found on mature foliage in autumn. However, this species is colonial, with 3-10 larvae (up to 3 cm long) commonly sharing a coarse cream web. Larvae overwinter. This strategy may allow the larvae to complete their development on new shoots in spring, which are significantly more nutritious than mature foliage (Hill 1982). There is evidence from the laboratory that adults prefer to lay eggs on old webs rather than gorse foliage (A.H. Gourlay unpublished data). Webs measuring up to 30 cm in diameter have been observed in the field in Portugal, surrounded by heavily damaged foliage. Such webs may have been occupied by successive generations of larvae. This species was released in New Zealand in 1995, and the details of this project will be published elsewhere. *P. genistella* has been released in 2 sites (Hayes *et al.* 1999) but establishment is not yet confirmed.

### ***Cydia succedana* (Denis and Schiffermüller), gorse pod moth**

The larvae of this tortricid moth feed on seeds within gorse pods. Each larva can destroy up to 3 pods. In Europe, *C. succedana* has 2 generations each year. Larvae attack *Ulex europaeus* in spring, and other species of gorse in autumn. *C. succedana* was selected for release in New Zealand to complement seed predation by the univoltine gorse seed weevil (Harman *et al.* 1996). Research into the host-specificity of *C. succedana* was completed in 1991, and the details of this research will be published elsewhere. *C. succedana* was released for the first time in 1992, and has become established. Moths are now abundant at the original release sites (Hayes *et al.* this symposium).

### **Biological control of gorse seed production**

*Cydia succedana* was selected as a control agent on the assumption that the second generation would attack the autumn crop of *Ulex europaeus* seeds. These seeds presently escape attack by *Exapion ulicis*, which is active only in spring. Detailed observations of the impact of *C. succedana* and *E. ulicis* on gorse seed production have been made at only 1 site. Contrary to expectations, moth densities peaked in spring rather than autumn (Suckling *et al.* 1999). It appears that most of the population in New Zealand is univoltine in spring, and the second generation is small. This is reflected in the infestation rates recorded at the site. The gorse there grows on a hillside spanning 100 m in altitude, and the flowering patterns vary with altitude (Hill *et al.* 1991a). At the bottom of the hill, gorse plants set seed only in spring. Here *Exapion ulicis* and *Cydia succedana* together destroy 90% (range 75-100) of the annual seed crop. At the top of the hill, gorse sets most seed in autumn. Here, *C. succedana* destroys 10-20% of the annual seed crop. *E. ulicis* is inactive at this time of year, and this seed previously escaped attack. Elsewhere in the site, gorse produces seed in both seasons, and the impact of the 2 insects on the annual seed crop varies. The altitudinal patterns of gorse seed production are repeated latitudinally in New Zealand (Hill *et al.* 1991a). Gorse growing in the far south of New Zealand sets almost all of its seed in spring. If the pattern recorded at this site is repeated nationally, reduction in the annual seed production of gorse growing in the south of New Zealand may be large. Conversely, the reduction in the annual seed production in more northern areas may not exceed 50%.

### **Biological control of green foliage**

Two of the 5 control agents introduced to attack gorse foliage (*Tetranychus lintearius*

and *Sericothrips staphylinus*) have established widely. *Scythris grandipennis* has not established. The status of *Pempelia genistella* and *Agonopeterix ulicetella* remains uncertain. Attempts to establish these 2 species continues (Hayes *et al.* this volume).

Heavy feeding by mites over consecutive seasons can kill individual shoots, and cause severe reduction in growth rates of plants in the third year (Partridge *et al.* 1999). Plants damaged in one season recover in the next if mite attack ceases. In 1 field trial, small plants infested with gorse spider mite for 2 yr were 18 % lighter than similar plants that were never infested (P. McGregor, personal communication).

When mites colonize new sites, populations grow rapidly, and cause severe damage to most plants. However, after several years populations decline rapidly, and never outbreak again. It is likely that such populations are being regulated by *Stethorus bifidus* Kapur, a predatory coccinellid beetle, and sometimes by *Phytoseiulus persimilis* (Phytoseiidae) (unpublished data). Large mite populations are now common in New Zealand, but these do not persist long enough, or in large enough numbers to provide adequate control of gorse. Gorse spider mites from New Zealand have since been released in California, Oregon and Hawai'i. It is not yet clear how populations will behave in those areas.

Although *S. staphylinus* has established widely in New Zealand, it is too early to assess the long-term impact of this agent on gorse populations. The damage caused by an individual thrips appears insignificant (Markin *et al.* 1996), but large populations can kill potted plants (unpublished data), and significantly reduce the growth rate of seedlings (Fowler and Griffin 1995).

### A bioherbicide for control of gorse in New Zealand

The potential for biological control of *Ulex europaeus* with fungi was raised by

**Table 1.**  
The role and status of insects and mites released for the biological control of gorse in New Zealand

Species	Family	Attacks	Released	Status
<i>Exapion ulicis</i> (Forster)	Apionidae	Seeds in pods	1931	Established almost everywhere
<i>Tetranychus lintearius</i> Dufour	Tetranychidae	Foliage	1989, 1991	Widely established
<i>Scythris grandipennis</i> (Haworth)	Scythrididae	Mature foliage	1990	Released at one site, probably not established
<i>Agonopeterix ulicetella</i> (Stainton)	Oecophoridae	Young foliage	1991	Released widely, establishment uncertain
<i>Sericothrips staphylinus</i> Haliday	Thripidae	Young foliage, seedlings	1991	Released widely, established
<i>Cydia succedana</i> (D and S)	Tortricidae	Seeds in pods	1992	Released widely, established
<i>Pempelia genistella</i> (Duponchel)	Pyalidae	Mature foliage	1996	Limited releases, establishment uncertain

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Johnston *et al.* (1995) who noted several endophytic species that might be developed as a mycoherbicide. One of these was *Fusarium tumidum*. This species was isolated from gorse stands throughout New Zealand, and a single isolate that was pathogenic to both gorse and broom (*Cytisus scoparius* (L.) Link) was selected for development as a mycoherbicide. Research into pathogenicity, toxicity, and formulation of this fungus is now well advanced (Morin *et al.* 1998), and is discussed further by Frohlich *et al.* (this volume).

## Discussion

Current research is concentrated in 4 areas. **Control agents** are being actively managed to ensure establishment as quickly and as widely as possible (Hayes *et al.* this volume). The development of a bioherbicide for gorse (and broom) continues (Frohlich *et al.* this volume). Hill (1996) discussed the importance of trying to predict the likely success of biological control programs by extrapolation from experimental studies, and the use of modelling. Experimental studies to measure the impact of individual control agents on gorse will be used, rather than the monitoring the impact of natural populations. Information on the ecology of gorse, either from specific studies (e.g. Hill 1999 ) or from the literature is being integrated to produce a spatially-explicit model of the population dynamics of gorse (M. Rees and R.L. Hill, unpublished data). This model will be used to predict the consequences of the current biological control program for gorse populations under different weed management regimes. In particular, it will address the role that seed-feeding insects might play. Several of the agents introduced for gorse control have measurable impact on individual plants, but none has yet demonstrated the ability to permanently suppress gorse in the field. The long-term impact of these species, acting alone or in combination, remains to be seen.

There are no plans to introduce further biological control agents for gorse until the status and likely impact of the 7 agents already established is clarified. However, other control agents could be considered in the future. Hill (1983) also summarized the potential for biological control and recorded 94 species of insects or mites attacking the plant, of which 16 were considered to be sufficiently host-specific to warrant further investigation. Zwölfer (1962) reported that in 40 samples of root material collected in western Europe, only 1 showed signs of damage, and there appear to be no root or stem-feeding insects in the natural range of gorse that are obvious candidates as control agents. The stem-galling weevil *Perapion scutellare* (Kirby) has been released several times in Hawai'i but has not established there (Markin *et al.* 1996). Zwölfer (1962) and O'Donnell (1986) observed terminal shoot galls formed by *Eriophyes genistae* (Nalepa) (Eriophyidae) in western Europe. *Scythris gallicella* de Joannis (Scythrididae) is a common foliage-feeding moth in the same area. An undescribed cecidomyid fly occasionally galls green shoots in Europe. The rust fungus *Uromyces pisi* forma specialis *europaei* (MacDonald 1946) is considered to be relatively specific to gorse, and permission to release it in Hawai'i has been sought (E. Killgore, Hawai'i Department of Agriculture, personal communication). These are the foliage-feeding species that may be appropriate control agents for use in New Zealand, although none are damaging in Europe. There may be better opportunities to further reduce the annual seed production of gorse. It may be possible to find populations of *C. succedana* where a greater proportion of the population is bivoltine, thus damaging a higher proportion of the autumn seed crop. There are a number of species of weevil that primarily attack autumn-feeding species of *Ulex* in Europe, that might attack *U.*

*europaeus* in autumn in New Zealand (Zwölfer 1962). Finally, there are natural enemies indigenous to New Zealand that might yet be exploited for biological control of gorse. The indigenous pyralid moth *Anisoplaça ptyoptera* Meyrick bores in gorse stems in New Zealand, and sometimes causes severe and widespread dieback in Canterbury. Similarly, a form of the stem-and bulb nematode *Ditylenchus dipsaci* Filipjev (Anguinidae) can be very damaging locally. Research into the distribution and identification of these species may identify opportunities for re-distribution to new areas within New Zealand.

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