

Infestation of gorse pods by *Cydia ulicetana* and *Exapion ulicis* in the South Island of New Zealand

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Summary

The effectiveness of *Cydia ulicetana* (Haworth) (gorse pod moth) and *Exapion ulicis* (Förster) (gorse seed weevil) at reducing annual production of gorse seed (*Ulex europaeus* L.) was compared at six sites over the South Island, New Zealand. The highest percentage (45%) of pods damaged by *C. ulicetana* was at East Takaka in May 2002, and *E. ulicis*, was most effective at Lake Ohau (76%) in January 2003. The percentage of damaged pods fluctuated. Although there were climatic differences among sites, they did not differ significantly in the proportion of gorse pods damaged by *C. ulicetana*. However, there was a significant seasonal difference ($P < 0.001$) over all observations and *C. ulicetana* was responsible for damaging approximately 20% of gorse pods.

Key words: Gorse, *Ulex europaeus*, gorse pod moth, *Cydia ulicetana*, gorse seed weevil, *Exapion ulicis*, effectiveness.

Introduction

Gorse (*Ulex europaeus* L.) has been a noxious weed in New Zealand since 1900 (Moss 1960). To combat gorse spread, various insect biological control agents have been introduced (Harman *et al.* 1996). *Exapion ulicis* (Förster) was first released at Nelson and Alexandra in February 1931 and the insect is now widespread throughout New Zealand (Kuschel 1972).

Female *E. ulicis* weevils lay eggs through a hole chewed in the side of an immature gorse pod. This hole closes and the hatching larvae proceed to destroy the seed in the pod (Hill *et al.* 1991). The adults are released from the pod when it dehisces (Hoddle 1991). *Exapion ulicis* larvae cannot move between gorse pods and must complete their development in the pod chosen by the adult female. Larval survival depends on adult oviposition (Hoddle 1991).

Weevils oviposit only in the spring. In many areas, the low availability of oviposition sites, coupled with intense pressure on female weevils to deposit eggs, leads to a very high percentage of weevil-infested pods in the spring and they can infest up to 90% of immature pods. However, seed produced at other times escapes attack,

especially where there is abundant autumn flowering (Hill *et al.* 1991).

To improve control of gorse seed production, *Cydia ulicetana* (Haworth) (previously referred to as *C. succedana* (Denis & Schiffermüller) (Fowler *et al.* 2004), was introduced into New Zealand in 1992 after completion of research into host-plant specificity in 1991 (Hill and Gourlay 2002). In Europe, *C. ulicetana* has two generations a year and larvae attack gorse seed in spring and the seed of other *Ulex* species in the autumn. The moth is now abundant in New Zealand at the original release sites such as Darfield, Canterbury (Hill and Gourlay 2002).

Cydia succedana lays its eggs on *Ulex*, *Genista*, *Sarothamnus* or *Lotus* plants in Europe (Emmet 1988) and it is assumed *C. ulicetana* does the same. In New Zealand, *C. ulicetana* completes both generations in the pods of *Ulex europaeus* and larvae are active from September to June, depending on the climatic conditions. The second generation over winters fully-fed from October (in Europe) in a cocoon spun in leaf-litter or the soil and pupates in the cocoon.

The insect is bivoltine in the south of the British Isles and is univoltine in Scotland (Bradley *et al.* 1979). A similar trend has occurred in New Zealand where the agent is univoltine in the cooler, southern regions, e.g. Mackenzie Basin, and bivoltine further north, e.g. Golden Bay.

The purpose of these studies was two-fold: first, to ascertain the percentage of gorse pods damaged by *C. ulicetana*; second, to determine the percentage of gorse

Pods damaged by the two seed feeders, *C. ulicetana* and *E. ulicis*, when both were active.

Materials and methods

Sample collection

Sites were chosen at Bainham, Onekaka, East Takaka, (collectively later referred to as Golden Bay sites), Hinewai, McLeans Island, Trotters Gorge and Lake Ohau (Figure 1). Fifteen gorse bushes were chosen randomly at each site. The starting point was selected without conscious bias and successive bushes were those at the distance given by a random number (in metres), from the previous bush in a straight line.

Gorse growth was dense at Hinewai, Onekaka and Trotters Gorge and formed a complete canopy, whereas at the other sites gorse bushes were scattered in pasture. Sites were inspected monthly and samples of 25 mature seed pods were collected, when available.

Climate data

From March 2002 to March 2003 the monthly average daily minimum and maximum temperatures (Figure 2) were recorded at all sites using thermo-hygrographs.

Plant phenology

In New Zealand, gorse grows profusely in many areas and a mean canopy height of 4 m has been recorded with a maximum height of 7 m (Lee *et al.*, 1986). The flower is pea-like, approximately 2 cm long and bright yellow with a distinct keel containing the stamens and stigma. A single branch 50 cm long can produce 500–1000 flowers over a two to three month flowering period (Markin and Yoshioka 1996).

Monthly sampling

Monthly observations were made of the proportion, in 5% steps, of the phenological stage of the gorse (i.e. the presence of buds, flowers, green pods and black pods) at the same time as sampling of pods. The number of damaged pods in each sample of 25 pods was recorded as well as the undamaged seed. An accurate count of the

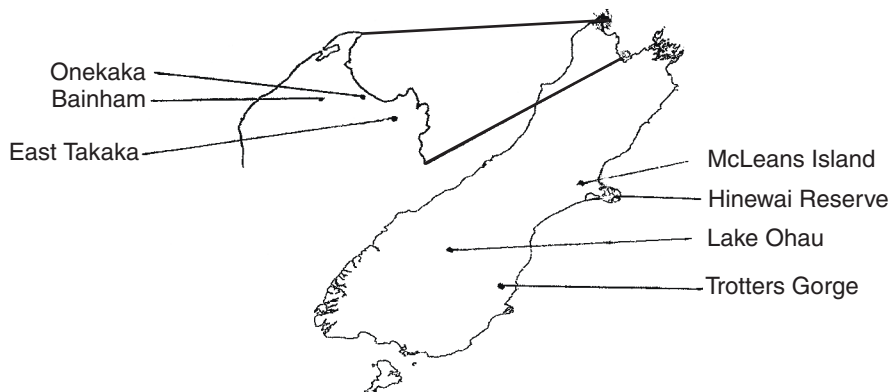


Figure 1. Map of the South Island, New Zealand showing the location of each sample site.

number of seeds damaged by *Cydia ulicetana* or *Exapion ulicis* was not obtained, however, calculating the average number of seeds in undamaged pods and multiplying this figure by the number of damaged pods gave an estimate of the number of seeds that were damaged each month.

Data collection and statistical analysis

Data were transformed using an arc sine transformation of percentages for analysis of variance with the SYSTAT 9 package. To compare among results at the different sites, two analyses were done. The first was among the Golden Bay sites over the whole study because this area differed in that plants bore seed pods for most of the year and *Cydia ulicetana* larvae were present for most of the year (Figure 3). The second analysis was a comparison among all the sites over summer when seed pods were commonly produced and both insects were present.

Results

Insect activity

Cydia ulicetana larvae were active at the Golden Bay sites throughout the winter until September to early October 2002 (Figure 3), when the damaged pods were sampled. There was no winter activity at the southern sites. Larvae began feeding again during mid-November 2002 at the Golden Bay sites. There was no activity at the southern sites during March 2002. Larval activity started in December 2002 and ended in January (Lake Ohau) and March 2003 at Trotters Gorge and Hinewai (Figure 4). *Exapion ulicis* larvae were active in November-December in Golden Bay and in December-January further south (Figure 3).

Flowering time

Gorse flowers and pods were present at all Golden Bay sites throughout the year presumably due to the milder climatic conditions (Figure 2). At Hinewai, Trotters Gorge and Lake Ohau gorse flowered only once and no gorse flowered in autumn – winter (April – September). At Lake Ohau, gorse flowered from September – October with some flowers still present in November. A high percentage of sample plants bore green pods in November. At Lake Ohau, mature pods were present in December and January, although there were few pods still unopened in January. Gorse seed production in undamaged pods was significantly different between Golden Bay and the other sites, with an average of 8.4 ± 1.9 SD seeds per pod, at the Golden Bay sites compared with an average of 4.1 ± 2.5 SD seeds per pod at the other sites ($P < 0.001$).

Pod damage and climate

Cydia ulicetana larvae destroy all of the seeds within a pod and then move out and

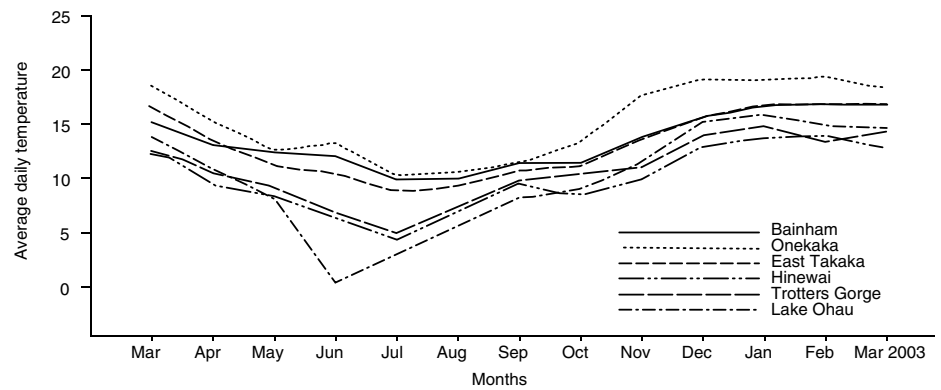


Figure 2. Monthly average daily temperatures at each experimental site.

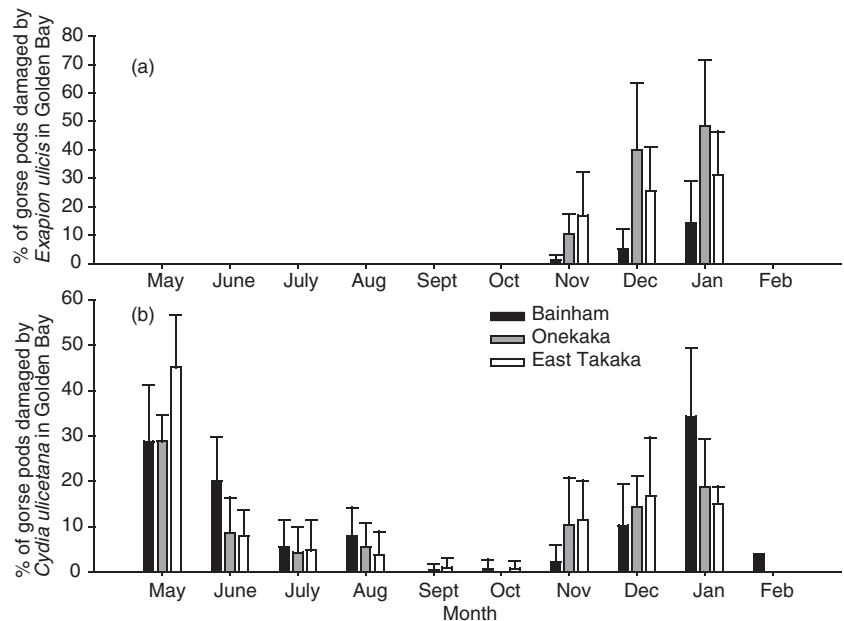


Figure 3. Percentage (\pm SD) of gorse pods damaged by insects at the Golden Bay sites. a) *Exapion ulicis*, b) *Cydia ulicetana*.

enter another pod. The highest percentage (45%) of pods damaged by *C. ulicetana* was at East Takaka (Figure 3) in May, (estimated to be 70 seeds per 25 pods) and 76% by *E. ulicis* at Lake Ohau in January (Figure 4), (estimated to be 39 seeds per 25 pods).

Although there were climatic differences between sites, there was no significant difference between sites in the proportion of gorse pods damaged by *C. ulicetana*. However, there was a significant difference between collection dates ($P < 0.001$). The site by time interaction was not significantly different ($P = 0.073$). At Hinewai, Trotters Gorge and Lake Ohau, where the insects were active for a shorter period, there was a shorter period of time when the monthly average maximum temperature was above 10°C (Figure 2), though ample pods were available (Sixtus 2004).

Discussion

Gorse seasonality

Gorse reproduction was limited by both altitude and temperature. In warmer

climates, buds develop and flower in autumn and winter, while in cooler climates, peak flower production can continue after the peak of weevil oviposition activity. Gorse reproductive development does not appear to be affected by day length, but by climate; seed production is seasonal (Hill *et al.* 1991). The position on the hillside affected plant phenology. The pod abundance peaked in autumn at the top and in spring at the bottom (Suckling *et al.* 1999). Ripe seed production was continuous at the Golden Bay sites from May 2002 to January 2003. Production at the southern sites was limited to December 2002 to March 2003; presumably the difference was due to the lower temperatures at the latter sites (Figure 2).

Seed production per pod differed. The Golden Bay sites had a higher average number of seeds per pod. The lower number of seeds per pod is attributed to the cooler and shorter growing season at the southern sites. The soil fertility could also contribute to the difference in the number of seeds per pod. Golden Bay sites

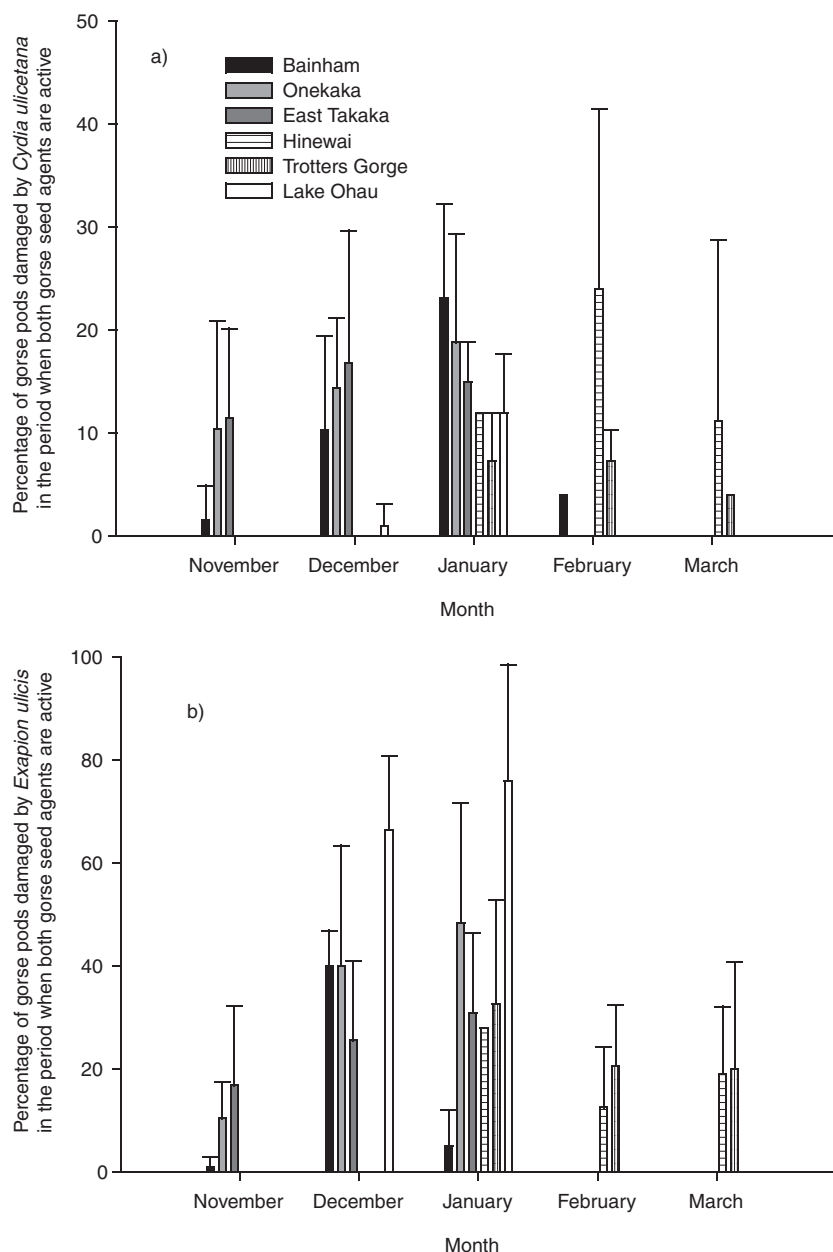


Figure 4. Mean percentage (\pm SD) of gorse pods damaged at all sites during summer (November – March) by a) *Cydia ulicetana* b) *Exapion ulicis*.

were on productive farmland and would be receiving fertilizer regularly. The southern sites, especially Hinewai and Trotters Gorge, would not receive any fertilizer as they were in reserves.

Establishment of *Cydia ulicetana*

Cydia ulicetana activity depends on temperature (Sixtus 2004). The cooler temperatures at the southern sites may have caused *C. ulicetana* to be univoltine as it is in Scotland, whereas at warmer sites, like Golden Bay, it is bivoltine as in the southern British Isles (Bradley *et al.* 1979).

Cydia ulicetana was released in Golden Bay in 1993 (R.G. Broadhurst personal communication). It was initially released on Banks Peninsula in 1992 (Hill and Gourlay 2002). The Mackenzie Basin saw releases in 1995–96 but there were no

releases at Lake Ohau (A.H. Gourlay personal communication). There have been no releases at Trotters Gorge but there have been several releases at the nearby Mt Herbert Forest (1992, 1994, 1995) (A.H. Gourlay personal communication). *Cydia ulicetana* has now been released sufficiently long enough in most of the areas to become well established. However, it appears that the winter cold in the southern regions (Figure 2) may have slowed the insect's establishment and spread (C.R. Sixtus personal observation).

Impact of *Cydia ulicetana*

There was seasonal variation at all sites in both gorse seed production and *C. ulicetana* activity. *Cydia ulicetana* larvae damaged a moderate percentage of pods in Golden Bay (Figure 3a), because of greater

larval activity, probably due to the warmer climate (Figure 2). Damage was very seasonal and it appears that the two periods when the most damage occurred were May 2002 and December 2002 – January 2003. These followed the main periods of gorse pod production of April and November 2002 respectively. *Cydia ulicetana* has better phenological synchronicity with gorse than *E. ulicis*, especially in Golden Bay. *Cydia ulicetana* has two generations a year in Europe (Bradley *et al.* 1979) and it appears that this is also the case in Golden Bay where the moth generations were synchronized with the gorse pod production (Figure 3a). From this work, based on the percentage of infested pods, it appears that the autumn generation of *C. ulicetana* had a greater impact at the Golden Bay sites. Suckling *et al.* (1999) found that, at Darfield, Canterbury, there was no synchrony between *C. ulicetana* and gorse during its recorded second burst of seed production in March/April 1997.

Combined agent activity

During November 2002 – March 2003, both insects were active in the areas surveyed. The results show that *C. ulicetana* was more effective for more months in warm regions (Golden Bay) than in the cooler, southern regions. During February and March 2003, there was a high percentage of gorse pods damaged by *C. ulicetana* at Hinewai Reserve (Figure 4). *Exapion ulicis* damaged a higher proportion of seed pods than *C. ulicetana* at the southern sites (Figure 4). This may have been because fewer *C. ulicetana* moths were present (C.R. Sixtus, personal observation). Either *E. ulicis* is better adapted to colder temperatures than *C. ulicetana* or it may simply be that *C. ulicetana* has not yet had sufficient time to build up its population in the south because of the lower temperatures, and the lack of direct releases at the Trotters Gorge and the Lake Ohau sites.

When there were insufficient gorse pods, *C. ulicetana* larvae fed on other legumes such as Scotch broom (*Cytisus scoparius*) and Russell lupin (*Lupinus polyphyllus* \times *L. arboreus*) (Paynter *et al.* 2004). The southern sites produced seed only in spring. Thus seeding plants could have experienced an increased attack from both *E. ulicis* and *C. ulicetana*, providing the insects' emergence was synchronized with gorse seed production. If synchronization is absent then there is a possibility that the effect of the pod herbivores would be reduced.

At Lake Ohau, a high percentage (76%) of gorse pods was damaged by *E. ulicis* during the two months that the gorse was producing mature pods. In the same period *C. ulicetana* damaged less than 10% of pods (Figure 4). The results indicate that >10% of gorse seed escapes predation by both of the insects even though gorse seed is only produced once in summer/autumn. This

maybe sufficient to maintain gorse plant replacement and continue gorse spread. Sixtus *et al.* (2003a) found 80% of undamaged gorse seed was viable. At Hinewai Reserve and Trotters Gorge, both *E. ulicis* and *C. ulicetana* were active from January to March. However, *C. ulicetana* damaged less than 10% of gorse pods while it was active at Trotters Gorge (Figure 4). At Hinewai Reserve, most damage by *C. ulicetana* was in March when 30% of pods were damaged (Figure 3). *Exapion ulicis* damaged approximately 20% of pods at both Hinewai Reserve and Trotters Gorge (Figure 4), i.e., half the seed production escaped damage by the two insects.

Hill and Gourlay (2002) showed that *C. ulicetana* larvae consume any *E. ulicis* larvae they encounter in pods. In a study of gorse seed predation in England, less than 20% of *U. europaeus* pods occupied by insects contained both species (Hill 1982). In this study, less than 5% of sampled pods contained both insects. However, several pods had *C. ulicetana* larvae, or they had been present, but there was no trace of *E. ulicis* though *E. ulicis* larvae were present in other pods. It is possible that *E. ulicis* larvae may have already been consumed.

For *C. ulicetana* to have a significant impact on gorse seed production, it would have to reduce seed production to a level where seedling recruitment was severely limited and the lifetime reduction of the seed bank would have to be great. Hill and Gourlay (2002) and Sixtus (2004) found that, after the larvae consumed all of the seed in one pod, they exited through round holes chewed in the side of the pod and sought another pod. Approximately 80% of larvae transferred to a second gorse pod, and 70% of those larvae pupated successfully (Hill and Gourlay 2002).

Gorse plants produce many pods each flowering season and up to 80% of the undamaged seed produced can be viable (Sixtus *et al.* 2003a). In addition, lightly weevil-damaged gorse seed, can still germinate (25%) (Sixtus *et al.* 2003b). With such high seed viability, the seed feeders would have very little impact on gorse plant abundance. However, if seedling survival is low, seed feeders can have a dramatic impact on the gorse abundance. At highly disturbed sites, young pre-reproductive gorse plants dominate the gorse population. This reduces the seed population because very few plants produce seed. Under these conditions seed feeders can have their greatest impact (Rees and Hill 2001). A high *C. ulicetana* population could mean that a high percentage of pods were infested. This would intensify competition between *C. ulicetana* and *E. ulicis* larvae. An aspect of competition between the two insects is the number of pods available; with a relatively low percentage of pods infested, there is an abundance of pods available. Thus we have not reached the

stage where the number of pods is a limiting resource. The competition between the seed-feeders is likely to intensify when the percentage of infested pods is high. Further research is required to confirm if *C. ulicetana* larvae do consume *E. ulicis* larvae and, if so, how many *E. ulicis* larvae are consumed.

Knowledge of the amount gorse seed damaged could also be used to help decide whether it was necessary to introduce further gorse seed-feeding biological control agents into New Zealand.

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