management strategies, particularly in identifying situations where biological control can be implemented,
- a network of trained officers who are able to advise farmers on the integrated management of St. John's wort and how biological control can be incorporated, and what to expect, and
- community participation and a sense of ownership of the implementation of biological control.

The networks also provide a pathway for the exchange of information between the Network Co-ordinators and co-operators and will enable other biocontrol agents for St. John's wort to be distributed should they become available in the future.

To successfully implement biological control throughout the entire distribution of St. John's wort in Australia, a good mapping and databasing system is required to identify areas which have not yet been targeted for biological control. Feedback from network co-operators on the progress of mites is important and needs to be encouraged in the future development of the network. Experience with this program has indicated that it is difficult to maintain a flow of information without the continued co-ordination and facilitation of Network Co-ordinators.

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Biological control of St. John's wort in New Zealand

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Summary

Three insect species introduced for biological control of St. John's wort (*Hypericum perforatum*) have established in New Zealand. They are two leaf-feeding beetles, *Chrysolina hyperici* and *C. quadrigemina*, and a gall-forming fly, *Zeuxidiplosis giardi*. The earliest introduction, *C. hyperici* in 1943, is the most common and widespread of the three, occurring on St. John's wort plants throughout their distribution. The second leaf-feeding beetle (first released in 1963) was not rediscovered until 1984, and occurs in mixed populations with *C. hyperici*. These St. John's wort beetles occasionally outbreak to very large populations, causing complete defoliation of host plants. *C. hyperici* seems to be the dominant species in New Zealand, and studies of the reproductive diapause of the two species indicate that this is because *C. hyperici*'s reproductive strategy is more successful in areas with colder winters. *Z. giardi* has a limited distribution in the northern part of the South Island, and where it occurs, plants appear stunted, with fewer flowers. There are no longer reports of areas in New Zealand where St. John's wort is a problem weed, and we conclude that successful biological control with insects is as least partially responsible for this change.

Introduction

New Zealand's biological control program for St. John's wort (*Hypericum perforatum* L., Clusiaceae) was an adjunct of the early part of the Australian program. As each of three insect control agents was introduced into Australia in the 1940s and 1960s, shipments were sent from Australia to New Zealand (Wilson 1943). The outcome of New Zealand's program has been somewhat different from the Australian experience, so the purpose of this paper is to review existing knowledge of the fate of St. John's wort and its three insect control agents in New Zealand.

Problem status of St. John's wort in New Zealand

The first record of St. John's wort in New Zealand was from Great Barrier Island in 1869, and the first record on the South Island was in 1896 (Jessep 1970). It is now widely distributed through the drier areas on the eastern side of New Zealand, and more common in the South Island than the North Island. From the 1940s it occupied large areas of pastoral land from the Awatere Valley in Marlborough to the Matukituki Valley in Otago. Miller (1970) reported it as 'a weed of considerable importance, particularly in the higher regions of low rainfall.' He described it as occurring in dense stands covering large areas, and displacing pasture species. Its toxicity to stock was also of concern. Connor (1977) noted that the greatest problem of photosensitization (caused by hypericin in the weed) was with high country sheep on the South Island, although cattle also suffered from the disease. It was particularly troublesome when mustering (stock losses occurred when animals were driven through water). In more recent years St. John's wort has gradually decreased in prominence. This has been partially attributed to changes in land management practices following substantial reduction in stocking levels on extensively grazed pastoral land. Fraser (1987) found that few districts in the South Island regarded St. John's wort as more than a roadside weed: in only one (Hakataramea) was the plant actively controlled on pastoral land. In the last decade the significance of the weed has declined further: no Regional Council reports it as even a minor problem (L. Hayes personal communication).

Introduction and establishment of biological control agents

Two leaf-feeding beetles and a gall-forming fly were introduced into New Zealand to control St. John's wort, and all three have established (Table 1).

Table 1. Species of insects introduced into New Zealand for biological control of St. John's wort.

Species	Origin	Date introduced
Chrysolina hyperici	Australia ex England	1943
C. quadrigemina	Australia ex France;	1963
	Canada ex USA	
	ex Australia ex France	1990
Zeuxidiplosis giardi	Australia ex California	
	ex France	1960–61

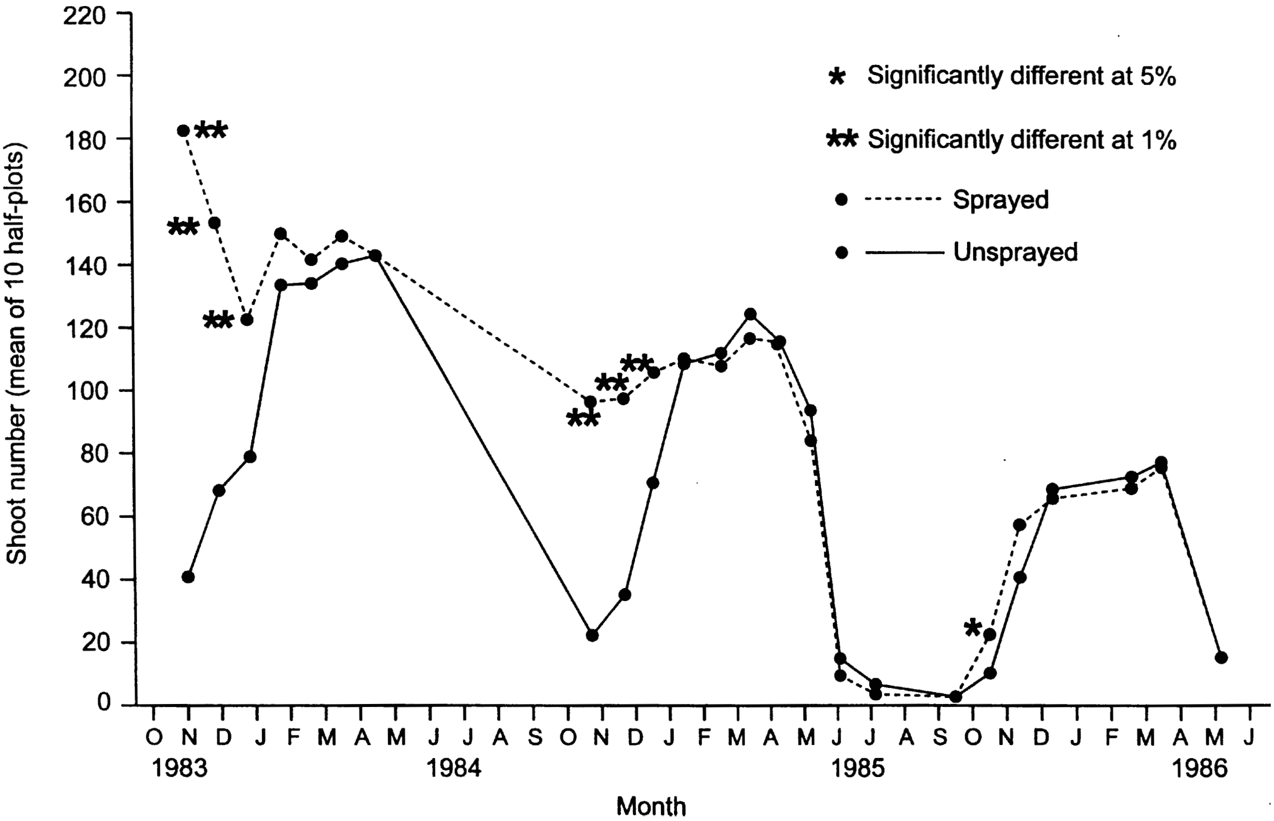

Figure 1. Numbers of stems of St. John's wort (mean) recorded in insecticide sprayed and unsprayed half-plots, Mt. Gerald Station, Lake Tekapo, 1983–86.

Chrysolina hyperici (Förster) (Coleoptera: Chrysomelidae)

Adult beetles of *C. hyperici* were imported from Australia in the summer of 1943 and after one day in quarantine, were released directly into the field (Miller 1970). By the following year there were large populations of beetles at the original release site in the Awatere Valley, Marlborough, and an 80 m^2 area cleared of weed. Over the next few years beetles were collected and transferred to areas throughout New Zealand (Hancox *et al.* 1986). They established readily on St. John's wort throughout its range.

Chrysolina quadrigemina (Suffrian) (Coleoptera: Chrysomelidae)

A second species of *Chrysolina* was introduced in 1963, and over 100 000 adult beetles were released in the period to 1968 at sites throughout the South Island (Hancox *et al.* 1986). Only one recovery of *C. quadrigemina* was reported during succeeding years: four males were collected at Ben Ohau in 1974. But in 1984 beetles were identified from widely separated sites in Central Otago and Marlborough (Fraser and Emberson 1987) and since then from a number of sites in between (unpublished data). In an effort to obtain beetles better adapted to New Zealand's climate, new material of *C. quadrigemina* from Canada was imported in 1990 and released in 1991. Releases were made at four sites, and *C. quadrigemina* beetles have been recovered from one of these, near Lake Benmore in South Canterbury. Mixed populations of the *Chrysolina* spp. beetles at Clyde, Central Otago, (from the earlier releases) comprised around 25% *C. quadrigemina* in 1991 (Schöps *et al.* 1996).

Zeuxidiplosis giardi Kieffer (Diptera: Cecidomyiidae)

Introductions of this gall midge were made in 1960–61, also from Australia. Difficulties were experienced in rearing the midge, and smaller numbers of flies were available for release than planned. Nevertheless, they soon established in a restricted area near Nelson, and subsequent releases were made throughout the South Island (Given and Woods 1964, Hancox *et al.* 1986). The gall midge has established well over a limited region in the northern South Island, including at an altitude of 830 m in north-west Nelson, but failed in other areas. No recent attempts have been made to spread the midge to other areas, partly because of difficulties in rearing the midge on St. John's wort plants under laboratory conditions. Early cultures for field release (by planting out infested plants) used *Hypericum pulchrum* L. because it was more amenable to laboratory handling (Given and Woods 1964).

Impact of biological control agents

C. hyperici

In parts of New Zealand *C. hyperici* was reported as spectacularly successful in controlling St. John's wort, but there were other areas where its impact was less marked (Hancox *et al.* 1986). An insecticidal exclusion trial was carried out from 1983 to 1986 at Mt. Gerald Station, South Canterbury to measure the effect of *C. hyperici* on stem production of St. John's wort (Syrett and Hancox 1985, Fraser 1987). Although total beetle numbers were relatively low at this site during the period of this experiment, in spring and early summer significantly more stems were counted in the plots protected from beetles than in those where beetles were present (Figure 1). A reduction in the growth of St. John's wort in spring is valuable to farmers because in many areas this weed is one of the earliest plants to produce new growth, and is heavily grazed then. A reduction in the amount of St. John's wort present in spring therefore reduces the chance of stock poisoning through preferential grazing (Fraser 1987). Field observations showed that early spring prostrate growth was heavily damaged by larval feeding, to the extent that few stems remained.

Relationship between C. quadrigemina and C. hyperici

Because *C. quadrigemina* occurs only in mixed populations with *C. hyperici* it is not easy to measure its impact on St. John's wort. Work described by Fraser and Emberson (1987) and Schöps *et al.* (1996) investigated differences in the reproductive diapause of the two *Chrysolina* species that might explain their relative success at controlling St. John's wort in New Zealand.

Laboratory experiments By subjecting adult *C. hyperici* that have just entered aestivation to four photoperiod treatments: short photo phase; long photo phase; short then long photo phase; and long then short photo phase under both moist and dry conditions, Fraser and Emberson (1990) showed that day length, rather than autumn rainfall, is the more likely trigger for the end of aestival diapause. Similar experiments by Schöps *et al.* (1996) with both *C. hyperici* and *C. quadrigemina* showed that under short days *C. quadrigemina* terminated aestivation about six weeks earlier than *C. hyperici*.

Field observations Schöps *et al.* (1996) sampled a mixed population of *Chrysolina* spp. at Clyde from early November 1991 to early April 1992. Beetles were dissected to determine the stage of their reproductive development. Results indicated that *C. quadrigemina* females began laying eggs in early to mid March, and *C. hyperici* in mid April. Schöps *et al.* (1996) suggested that differences in phenology resulting from differing responses to the onset of short days could explain why one *Chrysolina* species may be more successful than the other in a particular region. Eggs of *C. quadrigemina* hatch in autumn and larvae feed through the winter while *C. hyperici* overwinters in the egg stage. As the egg is the most cold-hardy stage, *C. hyperici* is well adapted to survive in regions with cold winters, while *C. quadrigemina* has the advantage that, in regions with milder winters, it can feed on available host plant material earlier than *C. hyperici*.

Zeuxidiplosis giardi

Given and Woods (1964) noted that the gall midge was most effective on young seedling plants, and on autumn and winter prostrate growth. Growing points attacked by the midge made no recovery, and growth of very young plants was arrested completely by only one or two galls. By 1967 patches of St. John's wort heavily infested with galls produced no flowers, and seedling plants were killed by midge activity (Given 1967). However, at that stage no parasitoids were found (Given 1967). Hancox *et al.* (1986) noted that *Torymoides* sp. (Hymenoptera: Torymidae) had been found in galls. It is not known what impact the parasitoid has on gall midge populations (Syrett 1989).

Discussion

Although in the years following successful establishment of *C. hyperici* in New Zealand reports indicated classic and spectacularly successful biological control, there remained areas where St. John's wort was cause for concern. Today, however, St. John's wort rarely builds to populations that become conspicuous. Since *C. quadrigemina* has generally been the more successful of the two *Chrysolina* species at controlling St. John's wort worldwide (Julien 1992), it is tempting to speculate that biological control has become more effective in New Zealand as *C. quadrigemina* populations have increased. The recent introduction of a more 'cold adapted' strain of *C. quadrigemina* from Canada coincided with the reappearance of *C. quadrigemina* in significant numbers from the 1960s introductions, possibly as a result of adaptation to the New Zealand environment. Shepherd (1985) noted that the proportion of *C. quadrigemina* relative to *C. hyperici* had increased over a 30 year period in Victoria, but that in Australia biological control of St. John's wort is not fully effective because beetles do less well in shaded situations. In New Zealand there is little lightly wooded habitat where St. John's wort might do well, but where beetles would be ineffective. Perhaps a balance has been achieved between numbers of the two *Chrysolina* spp. that results in better control of St. John's wort now than previously. The impact of *Z. giardi* is probably minor compared to that of *Chrysolina* spp. because its distribution is limited.

From being a major agricultural weed in the 1930s and 1940s, St. John's wort has become a roadside weed of only minor significance in the 1990s. Although we cannot directly attribute this change in status to insect biological control agents, there is sufficient evidence to conclude that they have been a contributing factor.

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