CHAPTER 8. ESTIMATING THE HOST RANGE OF A THRIPS PARASITOID

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BACKGROUND

New Zealand has recently adopted new legislation (The Hazardous Substances and New Organisms Act [HSNO] of 1996) governing the importation and release of new organisms, including insect biological control agents. The primary function of HSNO is to protect the environment, people, and communities from potential adverse effects of hazardous substances or new organisms. The introduction of the HSNO act has created a number of significant changes in the process for introduction of new biological control agents. For example, the introduction of a new organism requires a thorough assessment of possible risks, costs, and benefits, and there is more emphasis on consultation with concerned parties and potential negative environmental impacts on indigenous non-target hosts.

One of the first new organisms approved for release into New Zealand after this legislation was passed was *Thripobius semiluteus* Boucek (Hymenoptera: Eulophidae), a parasitoid of the greenhouse thrips, *Heliothrips haemorrhoidalis* Bouché. Before its release in New Zealand, an extensive research program was conducted to determine the host range of *T. semiluteus* and to 'demonstrate nil or negligible environmental impacts on New Zealand's flora, fauna, environment, and indigenous culture' as required under HSNO.

Some aspects of the information developed to support an application for the introduction of *T. semiluteus* are presented in this chapter. We first describe the ecology and biology of the pest and the proposed agent, followed by a description of the fauna in New Zealand potentially at risk from the introduction. Our principal focus in this chapter is to evaluate the as-

sumptions and logic that guided our testing program, technical aspects of the methods used, and our interpretation of the results obtained.

DESCRIPTION OF PEST INVASION AND PROBLEM

Heliothrips haemorrhoidalis (Thysanoptera: Thripidae; subfamily Panchaetothripinae), previous synonym *Thrips haemorrhoidalis,* is a ubiquitous species and has been recorded in 41 countries (Rivnay, 1935; Bodenheimer, 1951; Mound and Walker, 1982; Gerson, 1983; Ananthakrishnan, 1984; Goodall *et al.,* 1987; Beattie and Jiang, 1990; Kudô, 1992; Phillips, 1992; Dupont, 1993; Childers and Frantz, 1994; Phillips *et al.,* 1995). It is believed to have originated in South America in the Neotropics but is now widespread in tropical, subtropical, and temperate areas (Mound and Walker, 1982). *Heliothrips haemorrhoidalis* was first recorded in New Zealand in the 1930s and is presumed to have been accidentally introduced on imported plant material. It is abundant outdoors in the subtropical to temperate North Island and is found as far south as Christchurch in the more temperate South Island (latitude range in New Zealand of 36° to 44°) (Mound and Walker, 1982).

Heliothrips haemorrhoidalis is polyphagous and has been recorded on more than 60 species of plants worldwide (Ananthakrishnan, 1984) and over 30 in New Zealand (Spiller *et al*., 1982). Records from New Zealand are mostly restricted to subtropical fruit trees and cultivated garden trees and shrubs, with just two adults recorded from native forest areas (Mound and Walker, 1982). However, Martin and Mound (2004) have recently recorded small numbers of *H. haemorrhoidalis* in disturbed native forest and forest margins.

Heliothrips haemorrhoidalis is uniparental, with only females being produced. It is a significant economic pest in the subtropics and warmer temperate areas, where it occurs outdoors in very large numbers and can reproduce year round with several overlapping generations per year. In New Zealand, it is a significant pest on a number of commercial horticultural crops, including citrus and avocado (Figure 1). It has also been recorded as damaging nursery stock of two important forestry species, *Pinus radiata* D. Don and *Pseudotsuga menziesii* (Mirbel) Franco (Zondag, 1977). *Heliothrips haemorrhoidalis* has no effective natural enemies in New Zealand, and therefore growers rely on chemical or cultural control.

DESCRIPTION OF AGENT PROPOSED FOR INTRODUCTION

Thripobius semiluteus (Figure 2) was described in 1976, but earlier records exist of what is believed to be the same species based on specimens collected in Africa in 1931 and referred to as *Thripoctenus* (= *Ceranisus*) sp. This parasitoid has been recorded from tropical and subtropical areas of Africa, Asia, South America, and Australia. Research programs to determine the most efficacious and host-specific parasitoid for introduction against *H. haemorrhoidalis* have led to the introduction of *T. semiluteus* into California, Florida, and Hawaii (in the United States), as well as into Japan and Israel (Boucek, 1976; Hessein and McMurtry, 1988; LaSalle and McMurtry, 1989; Beattie and Jiang, 1990).

This parasitoid is a solitary koinobiont endoparasitoid that has been recorded from five species of thrips all within the subfamily Panchaetothripinae. It is uniparental (Loomans and

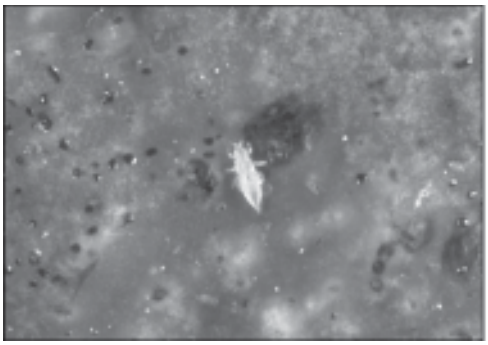

Figure 1. *Heliothrips haemorrhoidalis* adult and damage on avocado. Photo: M. Henderson. (UGA1295002)

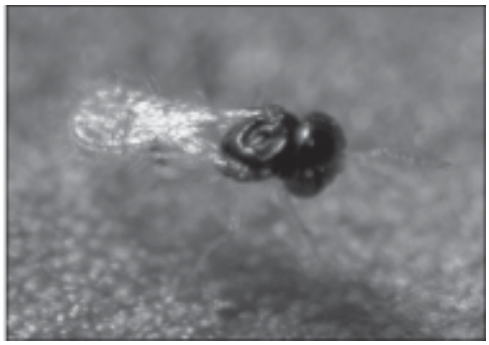

Figure 2. *Thripobius semiluteus* adult. Photo: D. Allan. (UGA1295003)

van Lenteren, 1995), and females oviposit single eggs into either first or second instar thrips (McMurtry *et al.,* 1991). When searching for hosts, the parasitoid walks in a slow sideways motion over the plant surface (Loomans and van Lenteren, 1995) and, on finding a suitable host, the female achieves oviposition in only 1-3 seconds before moving on to search for another host (Froud, personal observation). The parasitoid larva remains inside its host until the late second instar (just prior to the pre-pupal stage), when the host dies. The parasitoid then transforms into a black pupa, which remains cemented to the plant surface (where the host moves prior to pupation) until emergence of the adult parasitoid (Loomans and van Lenteren, 1995). The generation time for *T. semiluteus* at 23°C is 21 days, of which 11 days is spent in the pupal stage (Froud and Stevens, 1997). The adult longevity of *T. semiluteus* at 23°C is only 2.9 days, with the majority of eggs being laid on the second day following adult emergence (Froud and Stevens, 1997).

Source of agent *Thripobius semiluteus* was imported into the HortResearch insect quarantine facility at the Mt. Albert Research Centre, Auckland, New Zealand, in 1995 from F.A.R. Inc. Insectaries in Corona, California, USA. The *T. semiluteus* population in California was originally collected from parasitized *H. haemorrhoidalis* in Australia and Brazil. A subsample of parasitoids was checked by Frances Mafile'o, HortResearch, confirming that the shipment was free of insect pathogenic micro-organisms. Species identification and examination for hyperparasitoids were done by Dr. J. Berry, Landcare Research, Auckland, New Zealand, and voucher specimens were deposited with the New Zealand Arthropod Collection (NZAC), Landcare Research, Auckland, New Zealand.

Hosts in the native range of agent *Thripobius semiluteus* has been recorded as a parasitoid of five species of Thripidae, all in the subfamily Panchaetothripinae. LaSalle and McMurtry (1989) list *Brachyurothrips anomalus* Bagnall, *Panchaetothrips indicus* Bagnall, and *H. haemorrhoidalis* as hosts. Loomans and van Lenteren (1995) identified *Selenothrips rubrocinctus* Giard and *Hercinothrips femoralis* Reuter as additional hosts for *T. semiluteus*; however, parasitism of *H. femoralis* was only observed under laboratory conditions, never in the field. Of these five species of thrips, only *H. haemorrhoidalis* is known to be present in New Zealand.

THE RECEIVING LOCATION

Description of Fauna in Area of Proposed Agent Introduction

The thrips fauna of New Zealand is well documented (Mound and Walker, 1982, 1984) and includes a number of indigenous and invasive species. *Heliothrips haemorrhoidalis* is a member of the Thripidae, which is represented in New Zealand by two subfamilies, the Thripinae and Panchaetothripinae. *Heliothrips haemorrhoidalis* is in the Panchaetothripinae and is one of four species, in four genera, of this subfamily found in New Zealand (*H. haemorrhoidalis, Hercinothrips bicinctus* Bagnall, *Parthenothrips dracaenae* Heeger, and *Sigmothrips aotearoana* Ward). The first three are exotic pest (or potential pest) species. The last species, *S. aotearoana,* is a native thrips. In the other subfamily, Thripinae, there are 43 species in New Zealand, of which 18 are indigenous. Of the remaining 25 species, one – *Sericothrips staphylinus* Haliday – is an introduced weed biological control agent.

Local Species of Value as Biological Control Agents

Of the thrips species present in New Zealand, only one is considered of value as a biological control agent. *Sericothrips staphylinus* was introduced as a biological control agent to control gorse (*Ulex europaeus* L.), a severe weed of agricultural and natural lands in New Zealand. This thrips was introduced to New Zealand in 1989 from Europe. Later, new introductions were made with material from Hawaii (originally from Portugal). Due to the presumed restriction of *T. semiluteus* to thrips in the subfamily Panchaetothripinae, this Thripinae species was not considered a likely target for parasitism.

Displacement of native parasitoids and predators through the introduction of *T. semiluteus* was also considered as part of our studies. There are few natural enemies of thrips in New Zealand. Apart from one record of *Ceranisus* sp. from *H. haemorrhoidalis,* no other larval parasitoids are known for *H. haemorrhoidalis* in New Zealand (Mound and Walker, 1982; D. Steven, IPM Research, Auckland, New Zealand, unpublished data). A species of *Megaphragma* has also been recorded from *H. haemorrhoidalis* eggs; however, research has shown that it is not an effective parasitoid of *H. haemorrhoidalis* in New Zealand (Chhagan, 2002; D. Steven, IPM Research, Auckland, New Zealand, unpublished data). Several predators attack thrips in New Zealand, including three small solitary wasps in the genus *Spilomena.* These wasps capture thrips to feed to their larvae. One species of *Spilomena* has been recorded collecting large numbers of *H. haemorrhoidalis* larvae, but had little impact on thrips numbers (Mound and Walker, 1982). Two anthocorids (Homoptera), *Cardiastethus consors* White and *Cardiastethus poweri* White, also attack thrips in New Zealand (Lewis, 1973), as do some dipteran larvae and vertebrates. Also, several predatory thrips in the family Aeolothripidae and some ectoparasitic mites in the genus *Adactylidium* (Pyemotidae) can attack *H. haemorrhoidalis* (Mound and Walker, 1982). An *Entomophthora* species of fungus has also been recorded as infecting some species of thrips in New Zealand. None of these natural enemies, however, is effective at reducing *H. haemorrhoidalis* populations, and due to their generalist nature these species are unlikely to be displaced by the introduction of a larval parasitoid.

LOCAL SPECIES OF MARKED CONSERVATION VALUE

While there are no endangered or charismatic species that could be harmed by this introduction, some New Zealand thrips have unique interest as local products of evolution. *Sigmothrips aotearoana* was first described in 1970. It is a monobasic genus endemic to New Zealand and has only been collected from native forests. Only females have been observed. Adults have been collected in all months and are often found together with larvae in association with visible damage (Mound and Walker, 1982). Little else is known of the biology of S. *aotearoana,* other than that it lives mostly on seedlings of the indigenous plants *Coprosma* spp. and *Geniostoma ligustrifolium* Cheeseman and pupates in the soil (Mound and Walker, 1982; Froud, 1997). This is in contrast to *H. haemorrhoidalis*, which pupates on the host plant. The distribution of *S. aotearoana* in New Zealand is more extensive than that of *H. haemorrhoidalis* and includes a population in Southland (46° S, 169° E) (Mound and Walker, 1982). The Southland population is well beyond the known and potential range of *H. haemorrhoidalis* and *T. semiluteus*, respectively (43° S, 172° E) (Froud and Stevens, 1997).

THE TESTING PLAN: ANALYSIS OF METHODS

SPECIES LIST FOR HOST RANGE TESTING

Only members of the Panchaetothripinae seem likely to be within the host range of *T. semiluteus* in New Zealand because *T. semiluteus* has never been recorded from any species of Thripinae, despite rearing of these thrips to detect parasitism in areas where *T. semiluteus* occurs (LaSalle and McMurtry, 1989; Beattie and Jiang, 1990; Loomans and van Lenteren, 1995). Within the Panchaetothripinae, only two non-target species were selected for host range testing – *S. aotearoana* and *H. bicinctus* – because the only other member of the subfamily found in New Zealand – *P. dracaenae* – is an introduced pest. The target species – *H. haemorrhoidalis* – was included in choice tests and used as a control for comparison in no-choice tests.

Sigmothrips aotearoana was selected due to its conservation value as a monobasic genus and as an important member of New Zealand's endemic biodiversity. *Hercinothrips bicinctus* was subsequently included in the test list following low levels of parasitism of *S. aotearoana* by *T. semiluteus* in initial host range tests. Exposing the closely related *H. bicinctus* to *T. semiluteus* under the same laboratory conditions and experimental methods was done to assess the possibility that the low level of parasitism of *S. aotearoana* found in our tests was an artefact of confinement or imperfect host recognition (Michaud and Mackauer, 1995). *Hercinothrips bicinctus* is present in Australia, where it is sympatric with both *T. semiluteus* and *H. haemorrhoidalis,* but it has not been recorded as a host for *T. semiluteus* (pers. comm. A. Loomans, Wageningen, The Netherlands; M. Steiner, NSW Department of Agriculture, Australia; J. Noyes, Natural History Museum, U.K.).

GENERAL DESCRIPTION AND JUSTIFICATION OF TESTS

Both no-choice and choice host tests were carried out to estimate the host range of *T. semiluteus*. No-choice tests were undertaken to determine if *T. semiluteus* would use non-target species in

the absence of *H. haemorrhoidalis*. Choice tests were undertaken to determine if *T. semiluteus* would show a preference for *H. haemorrhoidalis* (if two species were available at the same time and place) and to determine the likelihood of non-target oviposition in a confined space where host cues could be commingled or at least spatially very close.

We also studied the life history and population dynamics of *S. aotearoana* and *H. haemorrhoidalis* to determine the likelihood of *T. semiluteus* encountering *S. aotearoana* and sustaining viable populations on this non-target host in the New Zealand environment.

Test #1: Host Testing of *T. semiluteus* against *S. aotearoana* and *H. bicinctus*

The goal of this test was to determine the ability of *T. semiluteus* to oviposit and successfully develop in *S. aotearoana* and *H. bicinctus*.

Methods for Test #1 Parasitoids used in tests were reared on *H. haemorrhoidalis* larvae on partially ripe lemons in sealed containers in a small, sealed room within the Insect Quarantine facility at 23C, 65-75% R.H., and a 16:8 L:D photoperiod. All host testing experiments were conducted within the same room under the same conditions. Five naive female parasitoids of a known age (24-48 hours after emergence) were introduced into a test arena (a clear, 3.5 liter plastic container, measuring 20 x 15 x 20 cm, with fine mesh ventilation) for both the choice and no-choice tests. Each comparison was replicated five times. *Heliothrips haemorrhoidalis* larvae were obtained from a colony reared in the laboratory on lemons. *Sigmothrips aotearoana* were reared in the laboratory from field-collected adults from *G. ligustrifolium* seedlings, and *H. bicinctus* larvae were obtained from field collections from Kapok vine, *Araujia sericifera* Brot. During exposure to parasitoids, *H. haemorrhoidalis* larvae were placed on a single lemon and the other test species were placed on their respective host plants (as described below). Thrips were transferred using a fine camelhair brush that was cleaned in 95% ethanol between species.

In no-choice tests, a group of five *T. semiluteus* females was exposed to either to (1) 50 first instars of *S. aotearoana* on a *Coprosma robusta* Raoul seedling (a common host plant of *S. aotearoana* that was readily available and could be kept alive during the experiment in a small flask stoppered with cotton wool and covered with Parafilm™—see Figure 3) or to (2) 50 first instars of *H. haemorrhoidalis* on an unripe lemon in the test arena. In choice tests, five *T. semiluteus* females were provided with 50 first instars of *S. aotearoana* and 50 of *H. haemorrhoidalis*, presented as described above. For both tests, adult parasitoids were removed after 24 hours and thrips larvae were separated by species and placed in containers to complete development. After two weeks, damp vermiculite was placed in the test containers with *S. aotearoana* to support pupation.

The methodology used in tests with *H. bicinctus* vs. *H. haemorrhoidalis* was the same as for the test with *S. aotearoana* vs. *H. haemorrhoidalis*, except that the *C. robusta* seedlings (the host plant for *S. aotearoana*) were replaced with black nightshade (*Solanum nigrum* L.) seedlings (the host plant for *H. bicinctus*). Damp vermiculite was provided for pupation of *H. bicinctus*. Also, five extra replications were added in the *H. bicinctus* vs. *H. haemorrhoidalis* choice tests due to low levels of parasitism for both species in two of the initial five replicates.

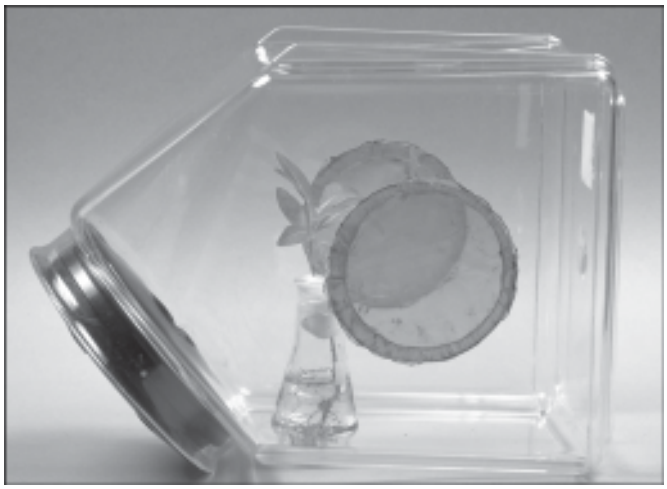

Figure 3. *Coprosma robusta* seedling in a no-choice test container. Photo: M. Henderson.

All experiments were assessed after 14-18 days. The numbers of adult thrips of each species and number of *T. semiluteus* pupae (recognised by their black coloration compared to the cream coloration of healthy thrips pupae) were recorded. Numbers of emerged adult parasitoids were recorded after 20-25 days. Statistical analyses for significant differences were performed using t-tests. Data were analysed using the SAS® statistical package. Percentages were subjected to angular transformation before analysis, but untransformed data are presented.

Results for Test #1 and analysis of problems In the no-choice tests with *S. aotearoana* and *H. haemorrhoidalis,* 92% (avg. 46/50) of the *H. haemorrhoidalis* larvae exposed to *T. semiluteus* were parasitized. By comparison, only 6% (avg. 3/50) *S. aotearoana* larvae were parasitized (Table 1). The percentage of parasitoids completing development and emerging as adults from *H. haemorrhoidalis* was very high (86-95%) and significantly higher ($P < 0.05$) than from *S. aotearoana* (37-53%) (Table 1). *Thripobius semiluteus* parasitized significantly more ($P < 0.05$) *H. haemorrhoidalis* than *S. aotearoana* under both choice and non-choice designs, and significantly more parasitoids completed development on *H. haemorrhoidalis* compared to *S. aotearoana* in each case (Table 1).

In the no-choice tests with *H. bicinctus* and *H. haemorrhoidalis,* there was no significant difference ($P > 0.05$) between the numbers of *H. bicinctus* and *H. haemorrhoidalis* parasitized (Table 1). The percentage of parasitoids completing development and emerging as adults from both hosts was very high and not significantly different ($P > 0.05$) (Table 1). When *T. semiluteus* was provided with a choice, significantly more ($P < 0.05$) *H. haemorrhoidalis* than *H. bicinctus* were parasitized. However, there was no significant difference ($P < 0.05$) between the percentages of resultant parasitoids completing development on *H. haemorrhoidalis* versus *H. bicinctus* (Table 1).

In both choice and no-choice tests, the non-parasitized larval and pupal mortality of *S. aotearoana* was very high at 76.9% (± 13.64 SE) and 98.6% (± 0.9 SE), respectively. As the larvae did not die in the first five days after exposure to *T. semiluteus* (most were at the prepupal

Table 1. Number (of 50) of *H. haemorrhoidalis, S. aotearoana,* and *H. bicinctus* larvae parasitized (mean ± SE) in no-choice and choice tests and percent emergence of adult parasitoids in each species.

Test	Thrips species	Number parasitoid pupae formed	% Emergence of adult parasitoids
No-choice	*H. haemorrhoidalis*	46.4 1.17 a[1]	95.29 1.38 a
	S. aotearoana	3.4 1.12 b	52.68 12.72 b
Choice	*H. haemorrhoidalis*	45.2 2.48 a	93.50 1.45 a
	S. aotearoana	4.4 2.32 b	36.79 12.10 b
No-choice	*H. haemorrhoidalis*	23.8 6.86a	89.03 3.13a
	H. bicinctus	16.8 2.94a	82.65 3.93a
Choice	*H. haemorrhoidalis*	23.1 6.11a	86.02 4.99a
	H. bicinctus	2.9 1.94b	44.67 21.49a

[1] Numbers from each test, within a column, with the same letter are not significantly different (T-test, $P < 0.05$)

stage or late second instars), it was assumed that the mortality was not caused by *T. semiluteus* host feeding on *S. aotearoana*. However, the cause of pupal mortality was further investigated (see Test # 2). Parasitism of *H. haemorrhoidalis* was higher in the earlier tests with *S. aotearoana* (45.2 and 46.4%) than in the *H. bicinctus* tests (23.1 and 23.8%). This may have been due to a drop in the fitness of the parasitoids over a prolonged period (14 months) of laboratory rearing.

TEST #2: SURVIVAL OF *SIGMOTHRIPS AOTEAROANA* UNDER TEST CONDITIONS

Methods for Test #2 To investigate if the presence of *T. semiluteus* caused the high level of *S. aotearoana* mortality seen during the host testing experiments, first instar *S. aotearoana* were held under the same conditions used in Test #1 (see above), except for the absence of *T. semiluteus*. Five replicates of 50 *S. aotearoana* larvae were placed on *C. robusta* seedlings in test arenas and held in the quarantine room for larvae to complete development. After two weeks, damp vermiculite was placed in cages with *S. aotearoana* for pupation. Once the late second instars started showing signs of pupating (stopping feeding and migrating down the seedling), the container was checked every 2-3 days for adults.

Results of Test #2 No *S. aotearoana* reached the adult stage. However, the larvae survived until the late second instar, when they migrated down the seedlings and attempted to pupate. Most *S. aotearoana* died as pre-pupae or pupae. A small number of larvae died in the first two days. This early larval mortality was most likely caused by handling. The failure of *S. aotearoana* to survive in the laboratory made it difficult to assess the potential impact of *T. semiluteus*. All 250 *S. aotearoana* larvae in Test #2 died before becoming adults. This happened in the absence of parasitoids and presumably was caused by physical conditions that were unfavourable for pupation.

TEST #3: POPULATION DYNAMICS OF *SIGMOTHRIPS AOTEAROANA*

Methods for Test #3 We made observations on the life history and field population dynamics of *S. aotearoana* over a 12-month period to detect unrecognized vulnerability to attack by *T. semiluteus*. A population of *S. aotearoana* was sampled in a four-hectare area of native forest in Auckland (41° S, 175° E). Five leaves on each of twenty randomly selected *G. ligustrifolium* seedlings were checked in situ for the presence of first or second instar larvae, pupae, and adults every two weeks.

Results of Test #3 No pupae were found on seedlings, suggesting that pupation occurred in the leaf litter. Adults were present on leaves throughout the year, but larvae were not present in winter, from early June to late October (1996). The population had a patchy distribution and thrips density was low, with a maximum of 1.0 thrips per leaf.

DISCUSSION

INTERPRETATIONS OF TEST RESULTS

Host testing showed that the endemic New Zealand thrips *S. aotearoana* is a potential target for parasitism by *T. semiluteus,* although the target pest, *H. haemorrhoidalis,* is clearly preferred. The low rate of *S. aotearoana* parasitism observed in our tests was not affected by the presence or absence of the target pest, *H. haemorrhoidalis*. *Thripobius semiluteus* also showed a preference for *H. haemorrhoidalis* over *H. bicinctus* in our choice tests. However, when the parasitoid was provided with *H. bicinctus* alone, the percent parasitism was equivalent to that when *H. haemorrhoidalis* alone was provided. Despite the apparent acceptability of *H. bicinctus* as a host for *T. semiluteus* under laboratory conditions, *H. bicinctus* is not known as a host in the wild in Australia where both species occur together (Froud and Stevens, 1998). Similarly, in the United States, *T. semiluteus* has been reared in *H. femoralis* under laboratory conditions, but it has never been recorded from this host in the field (Loomans and van Lenteren, 1995). These discrepancies between field and laboratory data suggest that laboratory data may not accurately reflect likely host/parasitoid interactions in the natural environment, and, in the case of *T. semiluteus,* our laboratory experiments appear to have overestimated the parasitoid's host range. Goldson *et al*. (1992) stated that the use of choice and no-choice tests in small cages can overestimate the potential field host range of a parasitoid. We suspect that confinement and/or poor host recognition by inexperienced females played an important role in the non-target parasitism seen in our tests.

Given the relatively high level of parasitism (6-34%) of *H. bicinctus* in our tests, the lack of such parasitism in the wild, and the relatively low level of parasitism (7-9%) of *S. aotearoana,* we concluded it is unlikely that *S. aotearoana* would be parasitized in the field. Unlike *H. haemorrhoidalis* and *H. bicinctus* populations in Australia, which are sympatric, *H. haemorrhoidalis* and *S. aotearoana* in New Zealand have very distinct habitats. The pest thrips rarely occurs in the native forest where *S. aotearoana* is found. This habitat separation between the two thrips species should decrease the chances of exposure of *S. aotearoana* to *T. semiluteus*.

Differences between the ecology and biology of *H. haemorrhoidalis* and *S. aotearoana* further decrease the likelihood of *T. semiluteus* establishing permanent populations on *S. aotearoana*. Whereas all life stages of *H. haemorrhoidalis* are present year round, *S. aotearoana* appears to overwinter only as feeding adults or possibly pupae in the soil. Reproductive diapause of *S. aotearoana* would reduce the ability of *T. semiluteus* to successfully establish in areas inhabited only by *S. aotearoana* as no host larvae would be available for parasitism for 4 to 6 months of each year. This implies *T. semiluteus* would need to re-colonize such habitats every spring, following the appearance of the native thrips larvae. *Thripobius semiluteus* is active year round in both California and Australia (Beattie and Jiang, 1990; McMurtry *et al.*, 1991). *Heliothrips haemorrhoidalis* occurs in large colonies with insects in overlapping life stages year round, on a wide range of host plants. Froud (1997) found up to 13 *H. haemorrhoidalis* thrips per leaf on the plant *Acmena smithii* Poiret, compared to one *S. aotearoana* thrips per leaf on *G. ligustrifolium* during the same sampling period. *Thripobius semiluteus* thus has access to large mixed-age colonies of *H. haemorrhoidalis*, which enables the parasitoid to oviposit in many larvae during its short lifespan. The low density and patchy distribution of *S. aotearoana* larvae, combined with this species' habitat separation from *H. haemorrhoidalis,* would further reduce vulnerability of *S. aotearoana* to attack by *T. semiluteus,* should any non-target parasitism occur.

SUMMARY EVALUATION OF THE ASSESSMENT

Completeness Our primary concern was to evaluate the potential for deleterious effects by *T. semiluteus* on indigenous thrips before introducing it to New Zealand. The level of host testing conducted was comprehensive given the parasitoid's very narrow recorded host range. A full Importation Impact Assessment (IIA) report was required as part of the application to import *T. semiluteus* into New Zealand. This report detailed our host-range studies and also discussed several developmental biology aspects of the parasitoid and its host that provided substantial evidence that the potential risk of *T. semiluteus* to indigenous species was negligible. The court hearing and public submission process provided a platform to present our scientific evidence with a high level of transparency.

One remaining concern is that the *T. semiluteus* colony used for New Zealand releases was from Italy (taken from Israel, previously taken from the United States) and potentially might not be the same 'biotype' as the one we tested. An attempt was made to obtain *T. semiluteus* directly from California, but *H. haemorrhoidalis* has become so rare in the field there that all local insectaries have ceased production of *T. semiluteus*. Several recent studies in New Zealand with other groups of parasitoids have shown large host-specificity differences, depending on the biotype introduced (Barratt *et al.,* 1997; Phillips *et al.,* 2002).

Ideally, all three test species should have been tested concurrently rather than 14 months apart because the fitness of *T. semiluteus* apparently declined by the time of the later experiments. Testing all species at once was not possible because of time constraints and the difficulty of rearing enough *S. aotearoana.* Host testing of *T. semiluteus* against *S. staphylinus* (gorse thrips) may also have been justified, given the value of this species in a weed biological control

program. However, conceding that this species should be tested, despite extensive evidence that it would not be a host, would have resulted in a requirement that *T. semiluteus* be tested against all 17 species of indigenous thrips species in the subfamily Thripinae. If this had been required, it is unlikely that the *T. semiluteus* biological control introduction program could have been undertaken.

Post-release evaluations *Thripobius semiluteus* was released into New Zealand in February of 2001 at 14 pesticide-free or organic citrus and avocado orchards and several home gardens. Monitoring in late summer of 2002 and 2003 at release sites showed that *T. semiluteus* is locally established at several sites. However, so far there has been very little spread of *T. semiluteus*, which generally has only been found in release sites and directly adjacent orchards. Due to this low rate of spread, it may be 6-10 years before any meaningful monitoring for parasitism of non-target species in natural situations can be undertaken. A research program to study effects on non-target species in a manipulated situation will, however, begin in 2004.

RECOMMENDATIONS FOR FUTURE WORK

Two main recommendations can be given from our tests; the first is that a control group of hosts (ones that are not exposed to the parasitoid) be included to detect any mortality associated with parasitoids, such as host-feeding. In addition, we suspect that in our system confinement contributed to non-target parasitism; therefore, it is recommended that larger cages be used for host range testing and that ventilation be increased to prevent mixing of plant or host volatiles from target and nontarget species. Also, field records of a lack of parasitism of one of the test species (*H. bicinctus* in Australia) were crucial in suggesting that the low level of attack on this species in our small-cage laboratory tests (and by extension similar attack on *S. aotearoana*) was most likely an artefact.

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