Enhanced biological control of wasps

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CONTENTS

Abstract

Sphecophaga vesparum burra (Hymenoptera: Ichneumonidae) has been released in large numbers at two sites—Binser Track in Arthur's Pass National Park and Tennyson Inlet in the Marlborough Sounds—as a biological control agent for wasps (*Vespula* spp.). As of winter 1999, 26 860 cocoons had been released and 9769 parasitoids (36.4% of total) had emerged. Emergence is likely to continue over the next 3 years. As yet there is no evidence of establishment. Smaller releases of *S. v. burra* have also been made at three other sites bringing the total number of cocoons released nationwide to over 33 000. Insertion of comb containing parasitoids into active wasp nests was trialled as an alternative release method to placing out overwintering cocoons. It was found to be a difficult and time-consuming method with limited success in getting the parasitoid to attack nests, and we do not recommend it as an efficient release method. Ecological comparison of *S. v. vesparum* and *S. v. burra* is incomplete, but the two subspecies are morphologically very similar. No further effort to release *S. v. burra* is recommended until there is evidence of establishment from existing release sites, and comparisons of *S. v. vesparum* and *S. v. burra* have been completed. As *Sphecophaga* is not yet confirmed as being established in the North Island, checking past *S. v. vesparum* release sites there is recommended before further North Island releases are considered. Measurements need to be made of the proportions of spring nests killed by parasitoid attack to be able to predict more accurately the eventual impact of *Sphecophaga*. Support of further development of inundative chemical and insect pathogen control strategies should continue as invertebrate biological control agents are unlikely to significantly reduce wasp abundance in the near future.

1. Introduction

Landcare Research introduced into quarantine *Sphecophaga vesparum burra* (Cresson) (Hymenoptera: Ichnuemonidae), a North American population of *S. vesparum*. The release and monitoring of *S. v. burra* at two sites and the comparison of the control potential of *S. v. burra* with the earlier released *S. v. vesparum*, from Europe, as been co-funded by the Department of Conservation (DOC) as part of a predominantly FRST-funded biological control programme for wasps (*Vespula* spp.) (Hymenoptera: Vespidae). The project was initiated in July 1995 with a planned 3-year time frame. Rearing difficulties have delayed progress and only the release phase of the project had been completed by June 1998.

2. Background

Wasps reach very high densities in New Zealand, particularly in beech forests with honeydew (Thomas et al. 1990). Ongoing research is demonstrating severe impacts from wasps in these forests (Beggs and Wilson 1991, Harris 1991, Toft and Rees 1998, Beggs and Rees unpubl. data); and that a reduction in wasp density of about 80% is required in order to mitigate the detrimental impacts (Toft and Rees 1998, Beggs and Rees unpubl. data). Current toxic baiting methodology can reduce wasp densities in localised areas by 55–70% and nest densities, within 100 m of bait stations, by 80–100% (Spurr 1993, Beggs et al. 1998). However, baiting is not feasible for widespread control because of the high labour costs.

Biological control is considered the only option that could achieve viable long-term suppression of wasp densities in native ecosystems because of the widespread nature of the problem. *Sphecophaga vesparum vesparum* (Curtis), a parasitoid of some social wasps (Vespinae), was the first biological control agent introduced against wasps (Donovan and Read 1987) and has been released throughout much of New Zealand since early 1985 (Donovan and Read 1987, Beggs et al. 1996).

In spring, *S. vesparum* females enter wasp nests and lay eggs on developing wasp pupae. The resulting parasitoid larvae feed on the wasp pupae, killing them in a few days. Parasitoid larvae pupate forming one of three types of cocoon (Donovan 1991). Fast-generation (white) cocoons are flimsy white structures that give rise to apterous females within 2 weeks. These females begin further oviposition within the host nest soon after emergence. Cocoons of the second type are slightly more rigid yellow structures that produce winged females and possibly males after 2 weeks. The third type are tough, yellow (overwintering) cocoons that produce winged females or males and which may spend up to 4 years in a dormant state before emerging. In late autumn and early winter, most wasp nests die out and the nest material generally decomposes rapidly. Overwintering parasitoid cocoons formed in the nest will remain in this subterranean cavity until their emergence from 1 to 4 years later. The more white cocoons produced, the greater will be the proliferation of the parasitoid within nests and the greater the impact on worker production, and possible colony survival. Production of overwintering cocoons ensures survival of the parasitoid from one wasp season to another.

Initial releases of *S. v. vesparum* were made via placement of overwintering cocoons in protected release boxes, and later comb containing white cocoons were inserted directly into nests (nest inoculations). The parasitoid is established at two sites (Beggs et al. 1996). At Pelorus Bridge in Marlborough, it became established from releases of cocoons only, while at the second site, Ashley Forest in Canterbury, both cocoon releases and inoculations were made (Beggs et al. 1996). When inoculated into nests, parasitoids emerge within several days and attack that nest. Any yellow cocoons produced can potentially overwinter in a natural situation for subsequent emergence. No data exist from previous *S. v. vesparum* releases on how successful nest inoculations are in achieving cocoon propagation within a nest, or whether it is a better release method than cocoon releases.

Initial predictions from modelling the wasp and parasitoid populations indicate that wasp densities may eventually be reduced by 10% (Barlow et al. 1996). Although encouraging, much greater reductions are required. Therefore, additional biological control agents need to be considered for adequate control to be achieved. *Sphecophaga vesparum burra* is the first alternate agent to be imported. It was imported from Western North America (Washington State and Northern Idaho). A total of 2081 cocoons were imported in 1979 and 1991, collected from the social wasps *Vespula artripilosa, V. vulgaris, Dolichovespula maculata* and *D. arenaria.*

There were three primary reasons for importing a second subspecies of *Sphecophaga*. Firstly, this second subspecies may establish in areas where the first has not because it is adapted to a different climate; secondly, the predictions from Barlow et al.'s (1996) model are that very small differences in the emergence patterns of cocoons could result in improved control; and lastly, because other potential invertebrate biological control agents do not look promising.

3. Objectives

- To determine the optimal timing, density, and method for parasitoids to be inoculated into wasp nests.
- To compare features of two subspecies of *Sphecophaga vesparum* influencing control potential.
- To summarise current knowledge on the establishment and predictions of success of *S. v. vesparum*.
- To release *S. v. burra* at two South Island sites and monitor establishment.
- To evaluate whether widespread release of *S. v. burra* is warranted.

4. Methods

4.1 RELEASES OF *Sphecophaga vesparum burra*

4.1.1 Permission to release

Host specificity testing was completed and an importation impact assessment (IIA) prepared (Appendix 1). The IIA was submitted to the Ministry of Agriculture and Fisheries (MAF) regulatory authority for public consultation on the application to release *S. v. burra* from quarantine into the New Zealand environment. Permission was also sought from the Minister of Conservation to release the agent onto public conservation lands.

4.1.2 Release sites

Previous releases of *S. v. vesparum* suggest establishment is favoured where there are high wasp densities and when large numbers of cocoons (>800) are released at a site (Beggs et al. 1996). Two release sites were chosen for large releases:

Binser Track: (Grid reference NZMS 260 L34 131999): a high elevation site (540–600 m) on the margin of beech (*Nothofagus*) forest and high country pasture. The forest is part of Arthur's Pass National Park at the beginning of the track to Binser Saddle. Honeydew is abundant and the site traditionally has high wasp densities (it had the highest abundance of wasps of 68 sites in DOC's nationwide wasp-monitoring network in 1990 (Beggs et al. 1990—Unpublished DSIR Land Resources contract report to DOC)). All release boxes were located within the forest.

Tennyson Inlet: (Grid reference NZMS 260 P27 740 093): a low elevation site (<30 m above sea level) centred around the Tennyson Inlet settlement. Release boxes were scattered up to a kilometre on either side of the settlement (Grid references of the two outermost boxes are P27 734097 and P27 744100). The release boxes were sited in a range of vegetation including: low manuka and ground ferns; sparse canopy of silver/red beech, tree ferns; damp gully vegetation—tree ferns, supplejack, nikau. Beech trees with honeydew are scattered throughout the site.

The Binser Track site was selected predominantly because of its high wasp density (i.e. to maximise the chance of the parasitoid encountering wasp nests) and high elevation (in comparison to Tennyson Inlet). Tennyson Inlet was selected because of its climatic similarity to Pelorus Bridge where *S. v. vesparum* has established. Both release sites had earlier releases of *S. v. vesparum*. At the Binser Saddle site, 800 cocoons of *S. v. vesparum* were placed in 1987 and 10 nests were inoculated in 1991. At Tennyson Inlet 600 cocoons were placed in the area in 1987 and a further 200 in 1991. Establishment of the parasitoid at both sites had not been determined.

4.1.3 Pre-release checks

To confirm that *S. v. vesparum* had not established at the proposed release sites, they were searched for prior to *S. v. burra* release. Establishment is defined as parasitoid cocoons being found in a nest other than one into which it had been directly inoculated. Nests within close proximity of the release boxes (< 2 km) were dug up and checked for signs of parasitism by visual inspection and uncapping of pupal cells within each layer of comb. The probability we would have detected establishment was calculated using the following equation.

$P = 1\text{-}x^y$ where x = 1- proportion of nests parasitised
(assumed to be 0.035, the lowest rate of parasitism at Pelorus Bridge)
y = the number of nests checked

4.1.4 Rearing of parasitoids

Sphecophaga vesparum burra cocoons were produced each summer at the Landcare Research insect-rearing facilities at Lincoln. The initiation of a rearing colony each season requires female parasitoids to emerge from overwintering cocoons in spring and lay eggs which produce white cocoons. Overwintering yellow cocoons were initially maintained in quarantine coolers at 5°C through

winter and warmed gradually in spring to initiate emergence. Once permission to release the parasitoid from quarantine was granted, half the yellow overwintering cocoons were maintained over the winter in a cooler and half in release boxes in a screen cage at Lincoln. Relying solely on 'natural' emergence from cocoons in a screen cage was too risky as these parasitoids emerged over a period of only a few days early in spring (October). At this time wasp comb is difficult to obtain because wasp activity has typically just begun and nests are very small. Cocoons maintained in the cooler could be warmed in late November and early December when wasp nests were more readily available.

Females emerging from overwintering cocoons were placed onto wasp nest comb, from which the workers and fully developed wasp pupae had been removed in order to maximise the life expectancy of the parasitoids. The comb was maintained at 28–30 °C. If only yellow cocoons resulted from oviposition by an emergent female parasitoid then parasitoid activity would cease for that season. Yellow cocoons result from parasitoid oviposition onto undeveloped pupae, while parasitoids cannot survive on fully developed wasp pupae (Harris and Rose, 1999). Obtaining white cocoons requires the presence of partially developed pupae. Therefore the age structure of wasp pupae in the comb they are placed onto and the oviposition choice of the parasitoid are critical. Eggs are not always laid and parasitoids do not always lay on the appropriate stage of wasp pupae for a white cocoon to result.

If white cocoons result, then emergence of the next generation of parasitoids occurs after about 14 days. These parasitoids are placed on fresh comb to repeat the oviposition process. Generally, once this fast generation phase has been triggered, maintaining the colony from generation to generation is assured, as these parasitoids lay more eggs than those emerging from overwintering. The main requirements for maintaining the colony once initiated are: a regular supply of fresh comb, daily removal of emerging parasitoids to new comb, and removal of wasps emerging from the comb. If high numbers of white cocoons result, then the size of the parasitoid colony increases rapidly.

4.1.5 Cocoon releases

Yellow overwintering cocoons (each cocoon contains a single parasitoid) were placed in soil inside release boxes. The release boxes were protected with wire-mesh-covered exit holes to prevent rodents eating cocoons. Boxes were placed in shady sites away from public view and revisited annually to record the number of parasitoids that had emerged from cocoons. Additional cocoons reared at Lincoln were added to the release sites each Autumn.

4.1.6 Nest densities

The density of wasp nests at each site was estimated annually by three people searching the same strip plot (10 m x 1300 m at Tennyson and 10 m x 1500 m at Binser). Measurement of nest density allows comparison of estimated wasp population between sites and years, and will enable later comparisons of nest densities if *S. v. burra* establishment occurs.

4.1.7 Establishment of *Sphecophaga vesparum burra*

Identical methods were used to check for establishment of *S. v. burra* as were used for pre-release checks of *S. v. vesparum* (see 4.1.3).

4.2 INOCULATION TRIALS

4.2.1 *Sphecophaga vesparum vesparum*

Due to delays in permission to release *S. v. burra* from quarantine, initial trials in summer 1996 to look at the effect of inoculum density on establishment success were undertaken with *S. v. vesparum*. Wasp nests parasitised with *S. v. vesparum* were dug from Pelorus Bridge and used to initiate a laboratory colony. Once the rearing colony was of a large size, comb was removed 9–11 days after parasitoids were introduced. Wasp pupae were removed from the comb so the number and type of parasitoid cocoon present could be seen. Comb for inoculation was split into pieces containing 0, 1, 5, or 10 white cocoons and a known number of yellow cocoons. Comb that had not been exposed to parasitoids was used as a control in the inoculation trial.

Fourteen nests at Awarawa Reserve (at the base of Mt Hutt) and 24 nests at Sharplin Falls Reserve (near Staveley), were inoculated with wasp comb sections on one of three dates between 4 March and 18 March 1996. To inoculate a nest the side of the nest is exposed, a section of comb from the nest removed, and the inoculum inserted into the space. The involucrum that has been removed is then put back in place and the nest covered up. Parasitoids were due to emerge from the inoculum within about 48 hours of insertion into the nest. Three weeks later nests were dug and incubated in the laboratory for a further 5–10 days before all cells were inspected for the presence of emerged parasitoids or intact white and yellow cocoons. The inoculum was inspected separately to determine the number of parasitoids that had emerged from cocoons.

4.2.2 *Sphecophaga vesparum burra*

Inoculation of nests with comb containing high numbers of *S. v. burra* parasitoids ready to emerge were conducted during the 1996/97 season at three sites (Binser Track, Tennyson Inlet, and Sharplin Falls). The exact number of white cocoons in each piece of comb prior to inoculation was determined for 11 of the nests inoculated at Binser Track. Nests were left until autumn. Initially it was intended to dig only a sub-sample of nests and leave the remainder at the release sites to contribute to the pool of cocoons from which establishment could occur, but the nature of the results lead to all the nests being dug and inspected for evidence of parasitism.

4.2.3 Comparison of inoculation methods

In March 1998, nests at Binser Track, Little River (Banks Peninsula), and Christchurch City were used to compare three inoculation methods:

- the standard inoculation method as described above;
- comb containing parasitoids nearing emergence were placed inside a plastic canister (50 x 25 x 100 mm) protected from workers in the nest. The canister was inserted between layers of comb and contained exit holes large enough for parasitoids to move into the nest after emergence;
- newly emerged female parasitoids were placed inside a plastic canister (50 x 25 x 100 mm) protected from workers in the nest. The canister contained exit holes large enough for parasitoids to exit into the nest.

Nests were left from 23 to 25 days, then dug and inspected for signs of parasitism.

4.3 COMPARISON OF SUBSPECIES

Field-reared cocoons of *S. v. burra* (from inoculation trials) and *S. v. vesparum* (from Pelorus Bridge) were collected and placed together in a release box at Lincoln to compare cocoon emergence patterns, a factor that Barlow et al.'s (1996) wasp population model predicts has a dramatic impact on success.

In addition, the morphology of adults of the two subspecies, and a third subspecies imported by Barry Donovan, were compared (Berry et al. 1997).

4.4 *Sphecophaga vesparum vesparum* UPDATE

The current status of *S. v. vesparum* was reviewed so it can be synthesised with experimental data on *S. v. burra* to allow recommendations as to whether or not further effort rearing and releasing of *Sphecophaga* is warranted.

5. Results

5.1 RELEASE OF *Sphecophaga vesparum burra*

5.1.1 Permission to release

Completion of host specificity testing in quarantine was delayed by 12 months due to difficulties, in 1994/95, in triggering the fast generation phase of the parasitoid's life cycle and so rearing sufficient numbers to complete the testing. Rearing was more successful in 1995/96, host specificity testing was completed, and the IIA (Appendix 1) was submitted to MAF on 21 March 1996. After completion of the consultation process, permission to release *S. v. burra* was granted on 22 September 1996. Authorisation to release the parasitoid into Arthur's Pass National Park and Tennyson Inlet Scenic Reserve was received from the Minister of Conservation on 9 September 1996.

5.1.2 Pre-release check for *Sphecophaga vesparum vesparum*

Fifty-five nests were dug at Tennyson Inlet in 1996 and 100 nests at Binser Track. There was no evidence of *S. v. vesparum* establishment at either site. Checking this number of nests corresponds to probabilities of 0.86 and 0.97 that we would have found *S. v. vesparum* if it was established at the two sites at the level of the lowest parasitism densities (3.5%) recorded at Pelorus Bridge (Beggs et al. 1996). If we add nests checked for *S. v. burra* establishment (see Table 3) the probability of finding *S. v. vesparum,* if present, rises to 0.99 for Tennyson Inlet and Binser Track.

5.1.3 Rearing of parasitoids

Sphecophaga has proven to be extremely difficult to rear. Triggering the fast generation phase from winged females emerging from cocoons has a high degree of uncertainty associated with it. The parasitoids from overwintering cocoons do not produce many eggs in the laboratory, and the majority of

cocoons produced by the parasitoid result in yellow overwintering cocoons that do not hatch that season. This is despite knowing that the stage of the wasp pupae is the key to the type of cocoon formed (Harris and Rose, 1999), and trying to remove other stages from wasp comb presented to parasitoids in spring. Production of white cocoons from parasitoid females emerging from overwintering cocoons is still the most difficult phase of the rearing process. To date we have succeeded in triggering the fast generation phase each season, but often only a few white cocoons have been produced from up to several hundred parasitoids emerging. As a result it can take several generations (with a turnaround time of about 2 weeks per generation) to produce a population large enough to supply parasitoids for experimentation. Throughout the rearing season (Dec–May) yellow cocoons are produced, which can be used for subsequent releases. Production of a large amount of wasp comb for inoculations is even more difficult, as removal of comb from the rearing colony for inoculation reduces the size of the colony available for subsequent rearing.

Once the fast generation is initiated the colony can rapidly build up in numbers, as it did in 1996/97 when over 25 000 *S. v. burra* cocoons were produced and material prepared for 82 inoculations. However, for unknown reasons, the colony can also prove very difficult to multiply, as occurred in 1997/98 when less than 1000 cocoons were produced during the season and adult and pupal parasitoid inoculum prepared for only 15 nests.

5.1.4 Cocoon releases

A total of 26 860 cocoons has been placed at the two release sites over three years (Figure 1, Table 1). At present adults have emerged from 9769 (36.4%) of those. More parasitoids have emerged from the Tennyson Inlet site, possibly due to the warmer lowland climate. Recent work has shown that cocoons in subterranean cavities emerged a season later than those in release boxes on the surface (Toft, Malham, and Beggs 1999). About 95% of *V. vulgaris* nests in beech forests are subterranean. Emergence from cocoons is likely to continue over the next 3, possibly 4, spring seasons.

TABLE 1. NUMBER OF *S. v. burra* COCOONS RELEASED AT BINSER TRACK AND TENNYSON INLET AND EMERGENCE UP TO WINTER 1998.

RELEASE SITE	YEAR	COCOONS RELEASED	TOTAL COCOONS AT SITE	CUMULATIVE NUMBER OF ADULTS EMERGED FROM COCOONS
Binser Track	1996	2600	2600	91
	1997	2300	4900	529
	1998	300	13200	3934
		+8000*		
Tennyson Inlet	1996	1597	1597	50
	1997	2508	4205	1160
	1998	1699	13660	5835
		+7756*		

* unemerged cocoons from 1997 production maintained in screen cage at Lincoln of first season.

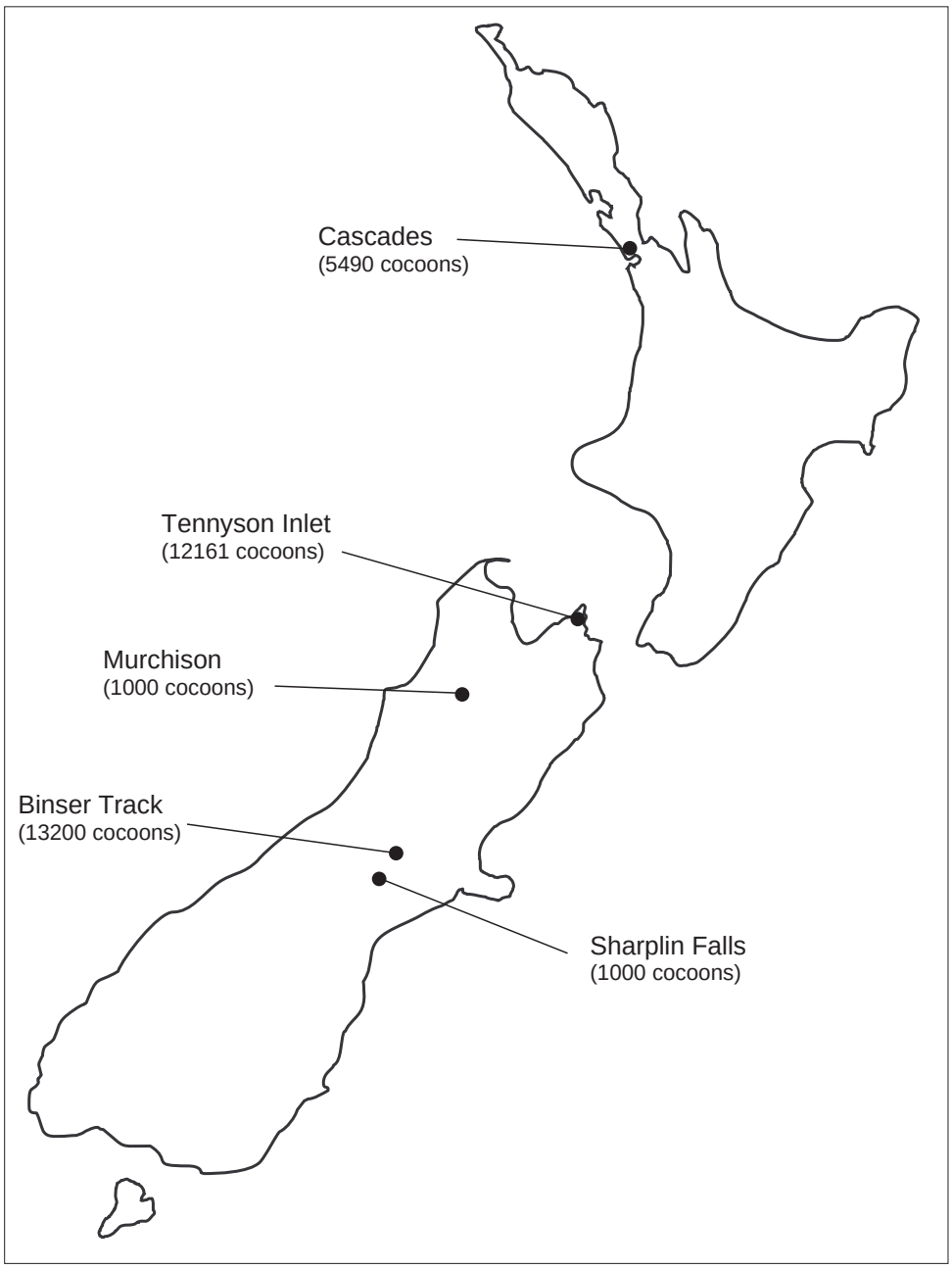

Figure 1. Location of sites where cocoon releases of *S. v. burra* have been made.

Additional releases of *S. v. burra* (Fig. 1):

- 1000 cocoons at Sharplin Falls near Staveley (Grid reference NZMS 260 K36 823 299) in the winter of 1997 in conjunction with the Staveley Community.
- 5490 cocoons at the Cascades site in the Waitakere Ranges (Grid reference NZMS 260 Q11 465 785) in conjunction with the Auckland Regional Council. An initial release of 990 cocoons was made in October 1996 by Barry Donovan. We released a further 4500 cocoons in winter 1997.
- 1000 cocoons at Ricky Leagh's property at Murchison (Grid reference NZMS 260 M29 606 334 and M29 606 349) in winter 1997 in conjunction with the Tasman District Council.

TABLE 2. FLUCTUATIONS IN ANNUAL WASP NEST DENSITY AT THE EXPERIMENTAL *S. v. burra* RELEASE SITES.

YEAR	NEST DENSITY (NESTS/ha) BINSER TRACK	TENNYSON INLET
1995	24.0	3.9
1996	10.6	0.8
1997	14.7	4.6
1998	9.3	8.5
1999	12.0	6.2

These smaller releases were made in conjunction with other organizations, but are relevant when considering whether further releases of *S. v. burra* are needed. No monitoring of emergence or establishment has yet occurred at any of these sites.

5.1.5 Nest densities

Nest densities at Binser Track were consistently higher than at Tennyson Inlet (Table 2).

5.1.6 Monitoring of establishment

No parasitised nests have yet been recovered from the release sites. However, only a small number of nests have been checked so far (Table 3) and a small number of parasitoids have emerged from the cocoons placed at both sites (Table 1).

5.2 INOCULATION TRIALS

5.2.1 *Sphecophaga vesparum vesparum*

Comb containing the initial inoculum was recovered from most nests after 3 weeks. In some nests inoculum was only partially recovered and/or traces of the cocoons had been removed by wasps (8% of yellow and 32% of white cocoons were not recovered). Emergence from white cocoons was high (93% of recovered cocoons). Very few parasitoids (<1%) emerged from yellow cocoons inoculated into nests.

TABLE 3. NUMBER OF NESTS CHECKED FOR ESTABLISHMENT OF *S. v. burra* AND PROBABILITY OF FINDING IT IF PRESENT IN A GIVEN YEAR (ASSUMING 3.5% OF NESTS ATTACKED

YEAR	NESTS DUG BINSER TRACK	TENNYSON INLET
1996/97	19(0.49)	-
1997/98	41(0.77)	63(0.89)

TABLE 4. INFLUENCE OF THE DENSITY OF WHITE COCOONS OF *S. v. vesparum* IN INOCULATED COMB ON NEST ATTACK AND COCOON PRODUCTION. MEAN ± SE.

COCOONS IN INOCULUM		NUMBER OF NESTS INOCULATED	NUMBER OF NESTS WITH ESTABLISHMENT	COCOON PRODUCTION IN NESTS WHERE ESTABLISHMENT OCCURRED	
WHITE	YELLOW			WHITE	YELLOW
10	43.0±7.2	9	4	8.8±5.5	28.5±6.6
5	18.9±5.4	8	4	8.7±3.9	37±29.9
1	10.5±4.5	8	3	0	6.3±5.3
0	34.0±3.1	4	0	-	-
0	0	9	0	-	-

Nest attack (the presence of any cocoons within the nest excluding the inoculum) was recorded for 11 of the 25 (44%) nests inoculated with white cocoons. Increasing the number of white cocoons in the inoculum did not appear to increase the likelihood of attack of a nest (Table 4). Low levels of inoculum (one white cocoon) resulted in no new white cocoons being produced, so if the nests were left longer there would be no further parasitoid propagation. Although highly variable, inoculum containing five or ten white cocoons per nest generally resulted in the production of more white (essential for continued parasitism within the nest) and yellow cocoons. If those nests with white cocoons present had been left to the end of the season greater numbers of cocoons may have been produced.

5.2.2 *Sphecophaga vesparum burra*

During the 1996/97 season we inoculated 82 nests. On average, for every two yellow cocoons that were recovered there was one white in the inoculum (Table 5). From the results of preliminary inoculations in the 1995/96 season, and with large numbers of whites likely present, we expected more than 40% of these nests to be successfully attacked and large numbers of cocoons produced by the end of the season. However, this was not the case. Only 9 nests (11%) were attacked and 134 new yellow cocoons produced (Table 6). The inoculum was recovered from most nests, but because nests were left until the end of the season, little evidence of whites remained. Extrapolating from the number of whites per yellow for the 11 nests checked prior to inoculations (Table 5), and the yellows found in the inoculum, we can estimate that there would have been about 19 white cocoons per nest. The very low establishment success was unexpected after the trials with *S. v. vesparum*.

TABLE 5. YELLOW COCOONS OF *S. v. burra* RECOVERED IN THE NEST INOCULUM FROM 11 NESTS INOCULATED AT BINSER WITH KNOWN NUMBERS OF WHITE COCOONS.

NESTS INOCULATED	WHITE COCOONS IN INOCULUM (MEAN ±SE)	INTACT YELLOW COCOONS RECOVERED FROM INOCULUM (MEAN ± SE)	NUMBER OF WHITE COCOONS IN INOCULUM FOR EVERY YELLOW RECOVERED
11	14.9±2.1	26.6±7.1	0.56

TABLE 6. SUCCESS OF *S. v. burra* PARASITOIDS IN ATTACKING NESTS FROM COMB INOCULATIONS.

SITE	NESTS INOCULATED	NUMBER OF COCOONS FOUND FROM WHICH PARASITOIDS HAD EMERGED	INTACT YELLOW COCOONS RECOVERED FROM INOCULUM MEAN ± SE	NUMBER SUCCESSFULLY ATTACKED	YELLOW COCOONS PRODUCED IN SUCCESSFULLY ATTACKED NESTS MEAN ± SE (TOTAL)
Binser Track	35	27	30.4 ± 3.9	8	15.3 ± 11.5 (122)
Tennyson Inlet	19	16	52.7 ± 9.9*	0	-
Stavely A	21	6	4.8 ± 1.6	0	-
Stavely B	7	0	38.7 ± 14.0	1	12

* 17.9 ± 6.3 chewed yellows also found.

5.2.3 Comparison of inoculation methods

The parasitoid attacked two of the fifteen nests in the trial of three inoculation methods (Table 7), and only very small numbers of cocoons resulted. Due to difficulties with rearing large numbers of parasitoids in the 1997/98 season, fewer replicates of each inoculation method were conducted than ideal. Therefore it was not possible to compare the three methods other than to say overall establishment in nests was low.

5.3 COMPARISON OF SUBSPECIES

To meaningfully compare cocoon emergence of the two subspecies, field-produced overwintering yellow cocoons are needed, as earlier work has shown that laboratory-reared cocoons emerge earlier than field-reared cocoons. Insufficient field-reared cocoons have been produced to complete comparison. Few *S. v. burra* cocoons (n = 134) were produced in inoculation trials and we did not find any establishment from cocoon releases (another potential source of field reared cocoons). The 134 cocoons produced in 1996/97 have been placed alongside 1996/97 *S. v. vesparum* cocoons collected from parasitised nests at Pelorus Bridge (n=185) in a release box at Lincoln to compare emergence. No emergence from either set of cocoons occurred in the 1997/98 season.

TABLE 7. EFFECT OF INOCULATION METHOD ON THE SUCCESS OF *S. v. burra* ATTACK OF WASP NESTS.

INOCULATION METHOD	CONTENTS OF INOCULUM WHEN DUG (MEAN ± SE)			NUMBER OF NESTS INOCULATED	NUMBER OF NESTS WITH ESTABLISHMENT	TOTAL COCOON PRODUCTION IN NESTS WHERE ESTABLISHMENT OCCURRED	
	ADULTS	WHITE COCOONS	YELLOW COCOONS			WHITE	YELLOW
comb	-	0	9.6 ± 4.6	5	1	1	1
protected comb	-	0.2 ± 0.2	14.8 ± 2.0	5	0	-	-
Adults	5	-	-	5	1	1	0

Comparison of the structural morphology of the two subspecies revealed no differences between them in any of the characters measured (Berry et al. 1997). However, there are consistent colour differences allowing reliable separation of adults of the two subspecies.

5.4 *Sphecophaga vesparum vesparum* UPDATE

Beggs et al. (1996) reported two sites of establishment of *S. v. vesparum*—Pelorus Bridge and Ashley Forest. Since then there has been only one additional report of parasitism. A single yellow cocoon was found in a nest in the botanical gardens in Christchurch (G. Watts pers. comm.). Large numbers of cocoons have been placed in the botanical gardens, including releases in the last few years. Until further parasitoid cocoons are found at this site, establishment cannot be confirmed.

Sphecophaga vesparum vesparum is continuing to spread from the initial points of establishment. It is estimated to be spreading at the rate of 1–1.5 km per year, based on measurements made at Pelorus Bridge (Barlow et al. 1998). Cocoons of *S. v. vesparum* are regularly being found in nests dug along the Canterbury foothills up to 24 km from the initial site of establishment at Ashley Forest.

Parasitism at Pelorus Bridge has not yet reached 20% of nests, nor is there evidence from nest density monitoring of any reduction in wasp nest density (Appendix 10.2). The 1997/98 season was the first year since the establishment of *S. v. vesparum* at Pelorus that nests have not been dug to measure parasitism rates. It is planned to continue to monitor the site, but less frequently than in the past.

Attack success within parasitised nests appears to be highly variable in self-sustaining field populations of the parasitoid. Over 110 yellow cocoons have been found in a nest attacked by parasitoids at Pelorus Bridge, but generally much lower numbers are found (61% of nests found contained fewer than 100 cocoons, mean of 157 cocoons, J. Rees unpubl. data). The only measurable impact on the nests that are parasitised is a reduction in the number of queen cells (Beggs et al. 1992—Unpublished proceeding of the 41st annual conference of the New Zealand Entomological Society). This is consistent with a nest model of wasp development which predicts this outcome following removal of a proportion of the worker force (D. Leathwick pers. comm.).

The probability of survival of overwintering cocoons and the pattern of cocoon emergence are two key variables influencing the ultimate suppression of wasp abundance (Barlow et al. 1996). Recent research has involved placement of overwintering cocoons in buried frames to simulate natural conditions, and monitored rates of cocoon predation by rodents, mortality from other causes, and emergence patterns (Toft et al. 1999). Rodents killed 62% of cocoons over 3 years, while flooding, insects, and unknown causes of mortality accounted for another 19.2%. The mean annual survival rate for overwintering cocoons was 56%, considerably higher than the model of Barlow et al. (1996) predicted. Emergence of cocoons in nest cavities was delayed in comparison with above-ground parasitoid release boxes, with the majority of subterranean cocoons remaining dormant until their third spring.

If the observed subterranean emergence pattern and an overwintering survival rate of 56% is applied to Barlow et al.'s (1996) model for the effect of the parasitoid, the predicted maximum suppression of wasp density is 25% (compared to 10%), but it will take 20–30 years to reach this level (Toft et al. 1999). However, this is an optimistic forecast that assumes 50% of parasitised nests are killed in spring. The proportion of parasitised nests that die in spring is currently unknown due to the difficulty of locating small spring nests in the field. If the rate of death of spring nests is assumed to be only 10%, the predicted ultimate suppression in wasp nest density falls to near zero (N. Barlow pers. comm.).

6. Conclusions

6.1 *Sphecophaga vesparum burra* ESTABLISHMENT

Releases of more than 32 500 cocoons have now been made at five sites. We have checked nests at two of these sites and found no evidence of establishment. However, it is premature to say whether establishment will occur because only a small proportion of cocoons have had adults emerge prior to checking a small number of nests at the two sites.

The five sites where releases have been made cover a broad range of environmental conditions. The two experimental sites have high numbers of cocoons released and relatively high wasp densities. We have nest density data collected using the same methods for six other sites in north-western South Island beech forests. Binser Track has the highest average density of the sites and Tennyson Inlet has the second lowest. The other release sites have moderate (Cascades) to high (Murchison) wasp densities and relatively high numbers of cocoons released compared to many of the sites where *S. v. vesparum* was originally released (generally <800 cocoons—Beggs et al. 1996).

At the two experimental release sites cocoons have been released over three consecutive years. We can therefore expect parasitoids to be emerging over a 5–6 year period, maximising the chances of favourable conditions if this is at all a limitation to establishment. In addition, three other sites have had at least 1000 cocoons released in a localised area. Therefore if *S. v. burra* is likely to establish in this country we would expect eventual establishment at one or more of the five sites. If the chance of establishment is so low as to not occur at any of these sites, then we suggest further effort with this subspecies is unwarranted.

6.2 RELEASE METHODS

The only difference in the inoculation method used for *S. v. burra* compared to that used for *S. v. vesparum* was that all wasp pupae were not removed from the inoculum prior to insertion—it was thought this would increase establishment as parasitoids would be hidden under pupal caps. However, the

11 nests that did have pupae removed showed similar levels of attack. Therefore we cannot rule out the possibility that there are differences between *S. v. vesparum* and *S. v. burra* in their ability to successfully attack nests from the inoculated comb.

Preparing comb for inoculation and conducting inoculations is difficult and time consuming. There are numerous drawbacks to this method:

- a specialist needs to do the inoculations at the nest;
- only a small number can be made in any season before the rearing colony is adversely affected;
- wasp nests need to be located at a site to be able to do the inoculations;
- comb has to be inoculated within a narrow time frame after production.

The hypothesised advantage of the inoculation method is that parasitoids emerge inside a wasp nest and produce cocoons in field conditions that can then overwinter in a natural state. However, attack success has proven to be low and, when the nest has been attacked, few cocoons resulted. Variable cocoon production within inoculated nests corresponds with results from the self sustaining population at Pelorus Bridge, where the number of cocoons produced is highly variable, but is generally higher than in our experiments—presumably because parasitoids attacked early in the season and had many more generations to increase in numbers in the nest. The few cocoons that are produced via inoculations will be subject to high risk of rodent predation at the end of the season and mortality from other causes. Also, the process of digging the nest may promote rodent attack. Rodent attack was suspected in five of the Binser Track inoculations (in one nest the inoculum was found a metre from the nest entrance).

Recent behavioural work on observation nests may explain some of the problems with the inoculation technique. When nests are disturbed by relocating them into observation nest boxes, there is a period of several days when worker behaviour is atypical and a large number of pupae are removed from cells and discarded from the nest (S. Harcourt pers. comm.). If similar behaviour is occurring in field nests when disturbed, then many parasitoids may be removed from the nest before they have a chance to emerge, especially if the inoculated comb is recognised as foreign. It was thought that placing the inoculum or parasitoid adults in protected containers may avoid this problem, but it did not increase parasitoid attack success. Similar difficulties have been experienced getting successful nest attack from inoculations using *S. v. israelensis* (D. Leathwick and B. Donovan pers. comm.).

Cocoon releases are much easier and have the advantage of protecting the initial cocoons from predation by rodents. With the same amount of effort, considerably larger numbers of cocoons can be placed at a site than can be achieved through inoculations. Due to the very low degree of establishment of *Sphecophaga* at release sites we cannot conclude that one technique is more likely than the other to result in establishment.

Cocoons do not have to be produced by starting up a rearing colony. *Sphecophaga vesparum vesparum* can now be redistributed by collecting them from nests at sites of establishment and then placing high numbers (> 1000 cocoons) in release boxes at new sites of high wasp density. Once established the parasitoid appears to be able to maintain the population and spread to surrounding areas.

6.3 SUBSPECIES DIFFERENCES

The two subspecies appear to be morphologically identical, with only colour differences separating them (Berry et al. 1997). Until *S. v. burra* establishes it is impossible to compare performance of the two subspecies. A third *Sphecophaga* has also been field released in New Zealand. Permission to release *Sphecophaga vesparum israelensis* was gained in 1997 (B. Donovan pers. comm.). This subspecies appears to be morphologically distinct from the other two (Berry et al. 1997). It principally attacks *Vespa orientalis* in Israel and although it readily attacks *Vespula vulgaris* and *V. germanica* in the laboratory, whether it will successfully attack these species in the field is unknown.

6.4 THE VALUE OF WIDESPREAD RELEASE OF *Sphecophaga vesparum burra*

We see no value in spreading *S. v. burra* further at present. There is no evidence of establishment at the two sites that have been monitored although a large number of parasitoids are still to emerge from cocoons at all five sites where it has been released. The best approach is probably to wait to see if establishment occurs, then determine if any subspecies differences suggest that greater effort with this subspecies is warranted.

Only two sites in the North Island have ever been checked for signs of *S. v. vesparum* establishment (Beggs et al. 1996). Until more likely sites of establishment (high wasp densities and large parasitoid releases) have been checked we cannot confirm their establishment status. Further effort in releasing at least one of the subspecies of *Sphecophaga* in the North Island may be justified if there is no evidence of establishment. Releases should centre around DOC sites that have regular wasp problems. Releases of field-collected *S. v. vesparum* would be the easiest and most economical way to make further releases.

6.5 FUTURE BIOLOGICAL CONTROL

Three subspecies of *Sphecophaga vesparum* have now been released in New Zealand. One, *S. v. vesparum*, is established and spreading (Beggs et al. 1996), *S. v. burra* has been released in large numbers at several sites (this report), and releases of small numbers of *S. v. israelensis* have recently begun (B. Donovan pers. comm.). Monitoring of the establishment and impact of these subspecies will continue, and some further releases are likely. Predictive modelling of the success of *Sphecophaga* is well advanced (Barlow et al. 1996). The key parameter missing that could enable us to accurately predict the success of *Sphecophaga,* is the proportion of spring nests killed by the parasitoid. However, if *S. v. burra* does as well or slightly better than the best predictions for *S. v. vesparum* (25% reduction in density), this will still be well below the 80–90% reduction estimated to be necessary for ecosystem protection in beech forests with honeydew (Toft and Rees 1998, Beggs and Rees unpubl. data). Therefore, other forms of control will still be required.

No other predatory or parasitic invertebrates of *Vespula* spp. from overseas appear to have the potential of *Sphecophaga* because they have very complex life cycles, often with a broad range of intermediate hosts. Furthermore, none appear to have the potential to kill colonies. Monitoring and comparison of *S. v. israelensis* along with the other two subspecies will indicate if any advantages are likely to be gained by further spread of a particular subspecies.

Insect diseases as agents for biological control of wasps are largely unexplored, with only a handful of records of disease being found within wasp nests (Rose et al. unpubl. data). Generalist pathogens are currently being developed for use against wasps (Harris et al. unpubl. data). They are likely to be used as an inundative control to replace chemical control, rather than used as a self-sustaining biological control agent. The potential advantages of pathogens over chemicals may include target specificity allowing aerial application, avoidance of environmental contamination issues, and the ability of the pathogen to multiply within colonies once a small amount gains entry. At present there are no known candidates for sustained, self-perpetuating control. It is therefore likely that inundative control will continue to be an important tool in controlling wasps in the foreseeable future, and advances in this field are required and achievable.

7. Recommendations

- Emergence of *S. v. burra* from cocoons should continue to be monitored at the release sites. Establishment at each site should be rechecked the season after no more emergence of cocoons from release boxes is recorded, or cocoons are removed. This would confirm that any parasitism resulted from females emerging from overwintering cocoons other than those released at the site.
- No more effort should be expended making further releases of *S. v. burra* in the South Island until results of initial releases are known and comparisons of the relative control potential of the different subspecies is completed.
- Further checking of sites in the North Island is needed to determine if *S. v. vesparum* is established there.
- Use of inoculations as a release method should be discontinued.
- Measurements need to be made of the proportions of spring nests killed by parasitoid attack using laboratory-reared colonies in order to be able to predict more accurately the eventual impact of *Sphecophaga*.
- Further development of inundative control strategies should continue as *Sphecophaga* has to date not reduced wasp abundance, and is unlikely to in the near future.

8. Acknowledgements

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Appendix 1

Introduction of *Sphecophaga vesparum burra* (Cresson) (Hymenoptera: Ichneumonidae) into New Zealand: An Importation Impact Assessment

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DATE: March 1996

Contents

1. Summary

This is an Importation Impact Assessment (IIA) prepared to accompany the proposal by Manaaki Whenua - Landcare Research to release *Sphecophaga vesparum burra* (Cresson) from quarantine into the New Zealand environment as a control agent to help suppress wasp populations (*Vespula* spp.).

- *Sphecophaga* has a wide distribution in Europe and North America. *S. v. burra* has a similar appearance and biology to that of *S. v. vesparum* which was studied extensively before and after being released in New Zealand.
- The host range of *S. v. burra* is restricted to some Vespid wasp species.
- *S. v. burra* populations imported into quarantine are free of any imported parasites or disease.
- MAF Quality Management has previously approved release of *S. v. burra* in 1979. This earlier attempt failed as a colony could not be maintained in quarantine and the six individuals released into the field failed to establish. *S. v. vesparum* was released in 1987 and large numbers have been liberated in New Zealand. Establishment is confirmed at two sites.
- Safety testing of *S. v. burra*, and previous testing of *S. v. vesparum* in New Zealand and Australia has confirmed that no other groups of social insects are at risk from this importation.
- It is intended that *S. v. burra* becomes distributed throughout New Zealand as part of a potential range of agents that will reduce the density of wasps (*Vespula* spp.) which are a major pest in New Zealand.
- Social, environmental and economic benefits would result from any reduction in wasp numbers. No environmental costs associated with release and establishment of *S. v. burra* are predicted.

2. Taxonomy

Order: Hymenoptera
Family: Ichneumonidae
Genus: *Sphecophaga*
Species: *vesparum*
Subspecies: *burra*

Six names have been applied to this insect in the past (*Anomalon vesparum*, *Tryphon vesparum*, *Cacotropa sericea*, *Sphecophaga thuringiaca*, *Encerous burrus*, *Sphecophagus praedator*), but Townes & Townes (1962) state there is only one species, *Sphecophaga vesparum* (Curtis) with a North American subspecies *S. v. burra* (Cresson), and a European subspecies *S. v. vesparum*

(Curtis). Another morphologically distinct population has been identified in Israel (Havron & Margalith in press), and its taxonomic status is currently under review.

Morphological comparisons of *S. v. vesparum* and *S. v. burra* have been made using standard techniques (light microscopy, SEM, morphometrics) (J. Berry et al. unpublished data). Both strains were raised on two *Vespula* wasp species and at different temperatures. No consistent morphological features distinguish males and females of one strain from those of the other strain. However, three colour characters gave >98% separation of the strains for females (not including the character originally used to define the subspecies) and seven colour characters gave 100% separation of the strains for males. Body colouration differences may not persist in field populations if interbreeding occurs between the two strains.

These findings raise questions as to the sub-specific nature of *S. v. vesparum* and *S. v. burra*. It may be more appropriate to consider the group as a single species with isolated populations.

3. Biology and Ecology of *Sphecophaga vesparum burra*

3.1 Distribution

S. vesparum has a wide natural distribution in Europe and North America. Establishment of *S. v. vesparum* is known to have occurred in two different regions of New Zealand. Releases of *S. v. vesparum* have also been made in Australia but establishment has not yet been confirmed.

3.2 Description and biology

The life cycle of *S. v. burra* is similar to that of *S. v. vesparum* which has been described in detail by Donovan (1991). Winged adults emerge from yellow overwintering cocoons from 1 to 4 seasons after they are produced. Mating can occur at this time, although females do not need to be mated to reproduce. Females locate wasp nests, enter and lay eggs into cells containing recently capped wasp pupae. The parasitoid larvae feed on the wasp pupae which are eventually killed. When feeding is completed the parasitoid forms either:

1. white cocoons that produce mostly brachypterous (wingless) females within about two weeks;

2. yellow cocoons that produce winged females (and possible males) within about two weeks;

3. yellow overwintering cocoons.

Wingless females emerging from white cocoons lay more eggs within the same nest, increasing the infestation in that nest. Winged females from yellow cocoons may either lay eggs in the same nest

or leave to attack other nests that same season. Parasitoids emerging from overwintering yellow cocoons ensure continuation of the parasitoid population from season to season.

3.3 Host range

Sphecophaga naturally parasitises some Vespid wasp species. *S. v. burra* cocoons currently held in quarantine in New Zealand originated from colonies of *Dolichovespula maculata* (L.), *D. arenaria* F. and *Vespula vulgaris* (L.) from Pullman, Washington State, USA. *S. v. burra* is also recorded from *V. atropilosa* (Sladen), *V. acadica* (Sladen), *V. vidua* de Saussure, possibly *V. maculifrons* du Buysson, *V. consobrina* (de Saussure), *V. pensylvanica* (de Saussure) (Donovan & Read 1987), and an unconfirmed record of a cocoon from a *Polistes* sp. (Townes & Townes 1962). In addition *S. v. vesparum* has also been recorded in nests of *V. germanica* (F.), *V. rufa* (L.), *D. saxonica* (F.), *Vespa crabro* L. (Donovan & Read 1987), and *Vespa orientalis* F. (Townes et al. 1965). New Zealand has no native Vespid wasps.

There are no recorded attacks on honey bees over the entire endemic range of *Sphecophaga*. The chance of *S. vesparum* attacking beehives and remaining undetected by beekeepers throughout Europe and North America is very small. No records exit of parasitism of any other insect by *Sphecophaga*.

3.4 Incidence of parasitism and disease

No parasitoids or predators have been identified from the *S. v. burra* colony that has undergone more than 20 generations in quarantine. Parasitoids from the original introduction in 1991 that had not emerged from cocoons by 1995 (the fourth season) were destroyed. A second importation by Dr Barry Donovan in early 1994 was also free of parasitoids and predators. Dr Peter Wigley (formally Hort-Research now Biodiscovery New Zealand) screened *S. v. burra* samples from both introductions and found no harmful pathogens present.

3.5 Likely distribution in New Zealand

If permission to release *S. v. burra* is granted, Landcare Research intends to rear the insect and initially release and monitor it at two sites. Further releases throughout New Zealand are likely if establishment occurs at these initial trial sites. From sites of establishment the parasitoid would spread naturally and eventually be distributed throughout New Zealand wherever wasp nests occur.

3.6 Expected impacts in New Zealand

Densities of *Vespula* wasps recorded in New Zealand are among the highest in the world. Nests generally have an annual cycle with queens establishing new nests each spring. Large fluctuations in wasp abundance occur from year to year. The favourable climate and absence of predators and parasites mean wasp nests are larger than those found in Britain (Fordham *et al.* 1991). Successful nests produce so many queens that 99.9% can fail to produce a new nest without the population

being adversely affected (Archer 1984). These characteristics make wasps a difficult target for biological control. A single agent is unlikely to have sufficient impact on the population to reduce ecological and social impacts of wasps. The appropriate strategy in such cases is to introduce a range of safe control agents which are complementary, and which together may reduce the abundance of wasps in New Zealand to acceptable levels.

One other biological control agent for wasps has been introduced from Europe so far. *S. v. vesparum* has been released throughout the country and establishment is confirmed at two sites (Moller *et al.* 1991, Beggs *et al.* in press). A model of the wasp and *S. v. vesparum* populations in this country suggests an ultimate level of suppression of around 10% will be achieved in areas where *S. v. vesparum* establishes successfully (Barlow et al. in press).

It is predicted that *S. v. burra,* originating from a region with a different set of climatic conditions, will increase the range of *S. vesparum* in New Zealand. In the absence of natural predators or parasites of its own, *S. v. burra* may become more abundant than it is in its native range. Whether the combination of *S. v. vesparum* and *S. v. burra* populations will reduce the wasp population more than *S. v. vesparum* alone cannot be predicted without further data on the characteristics of *S. v. burra* in the field in New Zealand.

3.7 Previous importations

In 1979, 798 cocoons of *S. v. burra* were imported into quarantine, a year before *S. v. vesparum* was first imported (Donovan & Read 1987). Four cocoons and two females were released into the field in Christchurch but no sign of parasitism was found. Subsequent attempts to produce adults from imported cocoons failed and the colony was extinct by late 1982.

4. Safety testing

4.1 Previous host range tests

Previous safety testing has been conducted with *S. v. vesparum* in New Zealand (Donovan & Read 1987). A total of 99 female *S. v. vesparum* were presented to honey bee brood (*Apis mellifera* L.) with and without adult honeybees present. No cocoons resulted when adult bees were present, as parasitoids were rapidly killed. Thirty *S. v. vesparum* released onto comb containing 1046 sealed cells of worker comb and 456 sealed cells of drone comb, without adult bees present, resulted in two yellow cocoons being produced from the drone cells. The bumble bee *Bombus hortorum* (L.) and the leafcutting bee *Megachile rotundata* (F.) were also tested but not attacked.

In Australia, *S. v. vesparum* was screened against a range of other members of the Vespidae family native to Australia (including *Polistes* sp.) and a stingless native bee species *Trigona carbonaria* Smith (Field & Darby 1991). Only two adult parasitoids were produced on *Ropalidia plebeiana*

Richards by presenting six parasitoids to 485 pupae. On *R. revolutionalis* (de Saussure), only one parasitoid was produced which died in its cocoon, from three parasitoids presented to 227 pupae. Sixty-nine cocoons resulted from the *V. germanica* comb presented in the choice test.

4.2 Host animals tested against *S. v. burra*

S. *v. burra* females were tested against honey bees, and the bumble bee *Bombus hortorum*.

4.3 Experimental methods

Newly emerged *S. v. burra* (Svb) females were presented to the following in no choice experiments.

- *V. vulgaris* worker comb containing at least 60 pupae (2 reps of 2 Svb)
- Honey bee comb containing at least 40 pupae (3 reps of 2 Svb)
- Honey bee comb containing at least 40 pupae + 10 newly emerged workers (3 reps of 2 Svb)
- 40 bumble bee (*B. hortorum*) pupae (6 Svb)

4.4 Results

S. v. burra cocoons were produced only when presented wasp comb containing pupae (55.5 ± SE 13.5).

4.5 Conclusions

Honey bees and bumble bees are not suitable hosts for *S. v. burra*. The experiments represent the worst case, i.e., comb without adults defending it. Despite this, no cocoons resulted. When adult bees are present parasitoids were rapidly killed. In the wild, undefended honey bee or bumble bee comb would not occur. These results, in conjunction with the failure of beekeepers in Europe or North America to find *S. v. burra* cocoons in bee hives, indicate that *S. v. burra* poses no risk to social insects other than wasps of the family Vespidae.

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5. Consequences of release

5.1 Social impacts

Any reduction in the number of wasps in the environment will have a positive impact on the quality of life of New Zealand residents and visitors. No negative social impacts are predicted.

5.2 Environmental impacts

S. v. burra is a host-specific parasitoid which only attacks some members of the social wasp family Vespidae. There is no significant risk of direct damage to the native flora and fauna of New Zealand. *S. v. burra* may seek carbohydrate from floral sources in spring when adults are searching for wasp nests, but this consumption is negligible when compared with that of introduced wasps.

Wasps reach high densities in a range of habitats but are most abundant in beech forest containing honeydew (Beggs et al. 1990). In beech forest they are a major competitor (Beggs & Wilson 1991, Harris et al. 1994), and predator (Harris 1991), of our native fauna. Any reduction in wasp numbers is likely to have immediate benefits in reduced impacts on invertebrate prey and increased availability of honeydew to birds and invertebrates.

A reduction in the number of wasp nests would reduce the use of insecticides to kill colonies and reduce insecticide loadings in the environment.

5.3 Economic impacts

S. v. burra poses no risk to economic crops or animals in New Zealand.

Direct economic benefits from successful biological control of wasps would likely accrue in increased production in the beekeeping (Clapperton *et al.* 1989), fruit growing, viticulture and tourist industries; reduced human health costs associated with wasp sting allergies (Dymock *et al.* 1994); reduced costs to Local Government, the Department of Conservation, and all land owners who presently undertake wasp baiting or colony poisoning (Spurr 1991).

Wasps eat predominantly flies, caterpillars and spiders (Harris 1991, Harris & Oliver 1993). Indirect costs associated with a reduction in predation on these groups may be an increase in the damage to crops from caterpillars and an increase in flystrike, but blowflies make up only a small proportion of wasp prey (Harris & Oliver 1993).

A small industry exporting wasp larvae to Japan could be adversely affected. The industry employs approximately five part-time workers processing wasp larvae, and additional people collecting nests.

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6. Conclusions

S. v. burra is part of a range of wasp natural enemies which could be introduced into New Zealand to help suppress wasp numbers. It has a narrow host range (Vespid wasps or the genera *Vespula*, *Vespa* and *Dolichovespula*) and could be introduced into New Zealand without risk to indigenous

flora and fauna or economic crops. A reduction in wasp numbers is a desirable outcome to preserve natural species and increase the profitability of a number of primary industries.

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Appendix 2

PARASITISM RATES AT PELORUS BRIDGE SINCE *Specophaga vesparum vesparum* FIRST BECAME ESTABLISHED, AND CHANGES IN NEST DENSITY AT PELORUS COMPARED WITH SIX SITES WHERE THE PARASITOID HAS NOT BEEN RELEASED. NO MEASUREMENTS OF PARASITISM RATE WERE MADE IN 1998.