Pheromone-mediated mass trapping and population diversion as strategies for suppressing *Carpophilus* spp. (Coleoptera: Nitidulidae) in Australian stone fruit orchards

David G. James*, Beverley Vogelet+, Richard J. Fauldert, Robert J. Bartelt, and Christopher J. Moore§

*Irrigated Agriculture Research and Extension Center, Washington State University, 24106 North Bunn Road, Prosser, Washington 99350, U.S.A. †Yanco Agricultural Institute, New South Wales Agriculture, PMB Yanco, New South Wales 2703, Australia. §USDA Agricultural Research Service, National Center for Agricultural Utilization Research, Bioactive Agents Research Unit 1815 North University Street, Peoria, Illinois 61604, U.S.A. §Queensland Department of Primary Industries, Animal Research Institute. Locked Bag no. 4, Moorooka, Queensland 4105, Australia

Abstract

1 Five experiments were conducted during 1995–99 in stone fruit orchards on the Central Coast and in inland New South Wales, Australia, on the use of synthetic aggregation pheromones and a co-attractant to suppress populations of the ripening fruit pests *Carpophilus* spp. (Coleoptera: Nitidulidae).

2 Perimeter-based suppression traps baited with pheromone and co-attractant placed at 3 m intervals around small fruit blocks, caught large numbers of *Carpophilus* spp. Very small populations of *Carpophilus* spp. occurred within blocks, and fruit damage was minimal.

3 *Carpophilus* spp. populations in stone fruit blocks 15–370 m from suppression traps were also small and non-damaging, indicating a large zone of pheromone attractivity.

4 Pheromone/co-attractant-baited suppression traps appeared to divert *Carpophilus* spp. from nearby (130 m) ripening stone fruit. Ten metal drums containing decomposing fruit, baited with pheromone and treated with insecticide, attracted *Carpophilus* spp. and appeared to reduce populations and damage to ripening fruit at distances of 200–500 m. Populations and damage were significantly greater within 200 m of the drums and may have been caused by ineffective poisoning or poor quality/overcrowding of fruit resources in the drums.

5 Suppression of *Carpophilus* spp. populations using synthetic aggregation pheromones and a co-attractant appears to be a realistic management option in stone fruit orchards. Pheromone-mediated diversion of beetle populations from ripening fruit may be more practical than perimeter trapping, but more research is needed on the effective range of *Carpophilus* pheromones and the relative merits of trapping compared to attraction to insecticide-treated areas.

Keywords Aggregation pheromones, *Carpophilus* spp. co-attractant, mass trapping, population diversion, stone fruit, suppression.

Introduction

Dried fruit, or sap, beetles in the genus *Carpophilus*, primarily *C. hemipterus* (L.), *C. mutilatus* Erichson and *C. davidsoni* Dobson, have recently emerged as major pests of stone fruit production in Australia (James et al., 1993, 1995). The reduction in broad-spectrum pesticide inputs in stone fruit production following development of pheromonal control of the key pest, oriental fruit moth, *Cydia molesta* Busck (Vickers et al., 1985), appears to have been the primary catalyst for elevation of these formerly secondary pests (Hely et al., 1982) to major pest status. *Carpophilus* beetles attack ripening fruit (primarily peaches, nectarines and apricots) causing rapid breakdown and also serve as carriers of brown rot (Kable, 1969). Economic losses can

Correspondence: Dr David G. James. Tel.: +1 509 7869280; fax: +1 509 7869370; e-mail: djames@tricity.wsu.edu
be severe and instances of total crop loss have occurred in a number of stone fruit growing areas in recent years. Current management of *Carpophilus* spp. is based on the use of broad-spectrum insecticides near harvest, although no insecticide is specifically registered for *Carpophilus* spp. and control is often poor.

Identification and synthesis of the male-produced aggregation pheromones of *C. hemipterus* (Bartelt et al., 1990a), *C. mutilatus* (Bartelt et al., 1993) and *C. davidsoni* (Bartelt & James, 1994) and subsequent demonstration of field activity (Bartelt et al., 1992, 1994a, b; James et al., 1993, 1994, 2000b), has highlighted the potential of these semiochemicals for nitidulid management in stone fruit orchards. James et al. (1996a) showed that perimeter-based mass trapping using synthetic aggregation pheromones can suppress *Carpophilus* spp. populations in stone fruit orchards. This study reports the results of further orchard experiments on the use of aggregation pheromones in protective mass trapping corridors or as a diversional tool to suppress *Carpophilus* beetle populations in stone fruit orchards.

**Materials and methods**

**Synthetic pheromones**

Pheromones for *C. hemipterus*, *C. mutilatus* and *C. davidsoni*, the major damaging *Carpophilus* spp. in Australian stone fruit orchards (James et al., 1993, 1994, 1995, 2000a), were used in these experiments. The pheromone for *C. hemipterus* consisted of a 100:31:11:8 blend of (2E, 4E, 6E, 8E)-3,5,7-trimethyl-2,4,6,8-decataetraene, (2E, 4E, 6E, 8E)-3,5,7-trimethyl-2,4,6,8-undecataetraene, (2E, 4E, 6E, 8E)-7-ethyl-3,5-dimethyl-2,4,6,8,9-undecataetraene, and (2E, 4E, 6E, 8E)-7-ethyl-3,5-dimethyl-2,4,6,8,9-undecataetraene, respectively (Bartelt et al., 1992). The pheromone for *C. mutilatus* consisted of a 100:7 blend of (3E, 5E, 7E)-5-ethyl-7-methyl-3,5,7-undecatriene and (3E, 5E, 7E)-6-ethyl-4-methyl-3,5,7-undecatriene (Bartelt et al., 1993). The pheromone for *C. davidsoni* consisted of a 100:9:31:160 blend of (2E, 4E, 6E)-5-ethyl-3-methyl-2,4,6-nonatetraene, (3E, 5E, 7E)-6-ethyl-4-methyl-3,5,7-decatriene, (2E, 4E, 6E, 8E)-3,5,7-trimethyl-2,4,6,8-undecataetraene, and (2E, 4E, 6E, 8E)-7-ethyl-3,5-dimethyl-2,4,6,8- undecataetraene (Bartelt & James, 1994). The synthetic pheromones were purified only by distillation and open end column chromatography on silica gel. These procedures did not remove the small amounts of Z isomers produced in the syntheses (Bartelt et al., 1990b), but there is no evidence that these (presently unavoidable) impurities are detrimental to pheromonal activity (Bartelt et al., 1992). Pheromone solutions were appropriately diluted with hexane and stored in a freezer until needed. Concentrations of components were determined by gas chromatography on diluted aliquots (instrumentation as described by Bartelt et al., 1990a). Pheromone solutions were applied to rubber septa (11 × 20 mm, red rubber, Aldrich Chemical Co., Milwaukee, Wisconsin) followed by 300 μL of methylene chloride. Once the liquid had soaked into the septa, they were aired in a fume hood for 1 h and stored in a freezer in tightly closed bottles until needed.

**Traps and coactractant baits**

Magnet funnel traps (Agriense, Pontypridd, Glamorgan, U.K.) were used to mass trap beetles in four experiments. This trap is a simple funnel type designed primarily for trapping moths. For trapping *Carpophilus* spp. we filled the trap with water to a depth of 2–4 cm and the pheromone septum and coactractant were taped to the inside of the downward projecting funnel. Water-based funnel traps were shown by James et al. (1996b) to be very effective in collecting large numbers of *Carpophilus* spp.

Monitoring of *Carpophilus* beetle populations was mainly conducted using the wind-orientated pipe trap of Dowd et al. (1992). This trap has been used in most *Carpophilus* spp. studies to date and is considered to be the most sensitive in terms of detecting changes in population density. A plastic bucket-type trap with a perforated lid (Lucitraps, James et al., 1996b) was used in experiment 4 as a monitoring trap.

Fermenting whole wheat bread dough (e.g. James et al., 1993, 1994) was used as the pheromone synergist (coactractant) in experiments one and two, and fermenting apple juice in polyacrylamide granules (James et al., 1998) in the remaining experiments. In experiments 4 and 5, ripe or decomposing stone fruit was also used as a coactractant.

**Experimental design and sites**

Five orchard experiments were conducted in New South Wales during 1995–99, examining the potential and efficacy of synthetic aggregation pheromones in suppressing intraorchard populations of *Carpophilus* spp. by perimeter-based mass trapping or attract and kill diversion.

*Experiment 1.* This experiment was conducted from 18 September to 29 November 1995 in an organic orchard at Mangrove Mountain (33°30' S, 151°19' E), near Gosford on the Central Coast of New South Wales. Synthetic aggregation pheromones (5 mg each of *C. davidsoni*, *C. hemipterus* and *C. mutilatus* pheromones per septum) were used to perimeter-based mass trap beetles to minimize damage to ripening fruit in a 65 × 15 m block of peaches (cv. Maravilha). A total 810 mg of *Carpophilus* spp. pheromone was deployed each fortnight. The block contained 90 trees at 2.5 m spacing in three rows 4 m apart and was surrounded by grassland on three sides and woodland on the fourth. Suppression traps baited with pheromone and coactractant were attached to the top of 54, 1.5 m steel posts which were placed at 3 m intervals around the block. Posts and traps were situated 5 m from tree canopies. To monitor intrablock *Carpophilus* spp. populations, three pipe traps baited with coactractant only were hung from trees 10 m apart in the centre row. Three coactractant only baited pipe traps were also used to monitor *Carpophilus* spp. populations in a nearby (15 m) peach (cv. Sherman) block (80 trees). *Carpophilus* spp. populations in the adjacent woodland were monitored using two pheromone (5 mg each of *C. davidsoni*, *C. hemipterus* and *C. mutilatus* pheromone) and coactractant-baited pipe traps hung from trees 25 m from the suppression block. Monitoring and suppression traps were initially baited on 18 and 27 September.
respectively, with all traps examined weekly until 29 November. Beetles in monitoring traps were forwarded to Yanco for counting and identification using Dobson (1954, 1964). An estimate of numbers of beetles collected in suppression traps was provided by counting drowned individuals as water was emptied from the traps. Coattractant baits were replaced in all traps weekly and pheromone septa were replaced fortnightly. Beetle damage to ripe fruit was assessed by examining, in situ, four randomly selected fruit on every tree in the Maravilha and Sherman blocks at weekly intervals during harvest (1-15 November). On 15 November, 120 fruit in a nectarine block 250 m from the suppression block, were also examined for damage and presence of Carpophilus spp.

Experiment 2. This experiment was conducted from 15 December 1995 to 5 January 1996 at Yanco Agricultural Institute in inland southern New South Wales (34°60'S, 146°40'E). A cordon of 62 pheromone (5 mg each of C. davidsoni and C. mutilatus pheromone) and coattractant-baited suppression traps on 1.5 m steel posts was used to suppress Carpophilus spp. in a small (25 × 25 m, 26 trees), unsprayed peach block (cv. Golden Queens). A total of 620 mg of Carpophilus spp. pheromone was deployed. Preliminary trapping indicated C. hemipterus was not present; thus the pheromone for this species was not used. Posts were spaced at 3 m intervals and were 10 m from the trees. Five pipe traps (coattractant only), hung in adjacent trees in the centre of the block, were used to monitor the intrablock beetle population. Five pipe traps per site were also used to monitor Carpophilus spp. populations in two nearby prune blocks (200 A and 370 m (B) from the peach block) and a citrus (cv Valencia) orchard, 650 m away. Trees in all blocks carried immature fruit at the time of the trial. Monitoring traps were deployed on 15 December and suppression traps on 22 December. All traps were examined weekly and serviced as in experiment 1.

Experiment 3. This experiment was conducted from 12 September to 22 November 1996 at the same organic orchard used in experiment 1. Once again, the intention was to protect the ripening Maravilha peach block from Golden Queens and C. mutilatus with ripening fruit to a high concentration of pheromone per fortnight provided a relative point source of pheromone in the orchard. Carpophilus spp. populations within the peach block were monitored from 19 February using six ‘Lucitraps’ containing six to eight ripe, damaged peaches. The traps were placed randomly within the orchard and located in tree crotches. Suppression traps were baited on 26 February and serviced as in previous experiments. The Lucitraps were examined weekly, beetles counted and identified and the fruit replaced. Peaches ripened and were harvested between 1 and 12 March. One hundred ripe fruit were examined in situ for beetle presence and damage on 5 and 12 March.

Experiment 5. This experiment was conducted in a commercial stone fruit/citrus orchard at Mangrove Mountain from 13 November 1998 to 13 February 1999. The aim was to attract or divert Carpophilus spp. from blocks of ripening stone fruit to a central insecticide-treated, high concentration pheromone source in open grassland. The orchard property covered an area of approximately 1000 × 500 m and comprised seven discrete blocks of stone fruit (13 varieties of peaches and nectarines) and three blocks of citrus (navel oranges) surrounding a 200 × 200 m area of pasture. The various stone fruit cultivars ripened at different times during November–February. The property was surrounded by and contained some natural woodland. Ten 180 L drums filled with decomposing, fallen stone fruit (coattractant), were placed in the pasture area. The drums were positioned within a 9 × 9 m zone and spaced at approximately 1.5 m intervals. Each drum was baited with 20 mg each of C. davidsoni, C. mutilatus and C. hemipterus pheromone, giving a total of 600 mg of Carpophilus spp. pheromone per fortnight for the 10 drums. Single, species-specific septa containing 5 mg of pheromone each, were used during the first 6 weeks; thereafter, single septa containing 5 mg of each of the three species’ pheromones were used (James et al., 2000b). Pheromone septa were held in a plastic cup attached to the inside of an upturned plastic plant pot suspended over each drum on a piece of wire. Fruit was added to the drums as necessary and a synthetic pyrethroid insecticide (tau-fluvalinate) was applied to the drums and ground in the drum zone at 10–14 day intervals to kill attracted beetles. Nineteen monitoring traps (coattractant only) were placed in the seven stone fruit blocks (two per block), in the two citrus blocks (three traps) and in open pasture just outside the property perimeter (two traps). Ten of these traps were within 200 m of the pheromone source. The other nine were at distances 250–500 m from the pheromone source. From 24 December until the end of the experiment, these traps were baited with coattractant and the pheromone of C. davidsoni (500 µg) (the dominant species in this district, James et al., 2001). In addition, two pipe traps baited with pheromone septa (5 mg each of all three species) and coattractant, were used to monitor beetle populations in adjacent woodland during the experiment. Drums, pheromones and monitoring traps were deployed on 13 November. Pheromone septa were replaced and traps serviced fortnightly. Estimates of fruit damage from Carpophilus spp. for each stone fruit variety and block were provided by the grower at the end of the experiment.
Results

Experiment 1. Perimeter suppression traps caught an estimated 94,240 beetles during the 4-week trapping period prior to commencement of the Maraviha harvest on 1 November. A further 14,200 were trapped during the harvest period (1–15 November) (Fig. 1). Despite the large numbers of *Carpophilus* spp. trapped on the perimeter of the Maraviha block, very few beetles were captured in monitoring traps within the block (Fig. 1). In addition, mean (± SE) fruit damage was 0.9% (0.4) with most damage recorded on 15 November (1.7%). No beetle damage was found in ripe fruit during harvest (15 October–1 November) in the nearby Sherman block. Very few beetles were caught in monitoring traps in the Sherman block (Fig. 1). No beetles or fruit damage were found in the distant (250 m) nectarine block on 15 November. The woodland monitoring traps (pheromone plus coattractant) captured 50–300 beetles/trap/week during the experiment. Most of these were *C. davidsoni* (> 95%).

Experiment 2. A much smaller population of *Carpophilus* spp. was present during this experiment. Suppression traps caught a total of 984 and 1,123 beetles on 29 December and 5 January, respectively. Intra-orchard monitoring traps also captured small numbers of beetles before and after deployment of suppression traps. However, there was a significant decline in captures after one week in the protected peach block and after 2 weeks in the two prune blocks (F = 8.6, d.f. = 3.19, P = 0.007; ANOVA; Fig. 2). No decline in numbers was observed in the distant citrus block.

Experiment 3. Perimeter suppression traps caught an estimated 16,740 beetles (> 95% *C. davidsoni*) from 9 October to 20 November (Fig. 3). Monitoring trap captures showed only a small number of beetles present during the experiment in the Maraviha and Sherman blocks. Numbers were lowest (0–2 per trap/week) during harvest (Fig. 3). No beetles were captured in the nectarine block, whereas an average of 27 beetles/trap/week were collected in the nearby commercial orchard. No beetles or beetle damage were detected in ripe fruit on 23 October and only 0.7% of examined fruit had beetles and damage at the end of harvest on 6 November.

Experiment 4. A small population of *Carpophilus* spp. was present during this experiment with only 752 beetles captured in suppression traps during the 4-week trapping period. Similarly, low numbers of beetles were collected from the Lucitraps baited in the peach block. However, significantly fewer beetles were found in the baits after suppression trapping commenced and numbers declined further during 5–19 March (F = 6.7, d.f. = 4, P = 0.005; ANOVA; Fig. 4). No damage was detected in ripe fruit examined on 5 and 12 March.

Experiment 5. At the commencement of this experiment on 13 November, *Carpophilus* beetle damage was already occurring in early ripening fruit (harvesting began on 1 November). The insecticide, fenthion, was applied by the grower in affected blocks. 'Swarms' of *Carpophilus* were observed flying over the fruit drums within hours of pheromones being deployed. No beetles were captured in the coattractant-only monitoring traps from 13 November to 24 December, prompting the use of pheromone plus coattractant in these traps from 24 December to 13 February. From 13 November to 16 January 100–150 beetles per fortnight were trapped in the two pheromone/coatractant traps in adjacent woodland. Economic losses from *Carpophilus*
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Figure 3: Carpophilus spp. caught in pheromone (total 810 mg/fortnight) and coattractant-baited suppression traps (n=54) placed around a Maravilhas peach block (3m spacing) and in coattractant-baited monitoring traps (three traps per block) within the block and in a nearby (15m) Sherman peach block (experiment 3).

damage continued from 13 November to 24 December as did grower-applied sprays in an effort to manage populations. From 24 December to 13 February, significantly greater numbers of Carpophilus spp. were trapped in monitoring traps located within 200 m of the concentrated pheromone source/fruit drums than in traps located more than 200 m away (means: 67.7 ± 12.0, 17.3 ± 4.0, P < 0.01; t = 3.92, d.f. = 18, P < 0.001; t-test; Fig. 5). Carpophilus davidsoni was the dominant species trapped (72% of captures) with Carpophilus gaveni Dobson and Carpophilus marginellus Motschulsky comprising the remainder. Estimated damage to ripening fruit was significantly greater in varieties located within 200 m of the pheromone source (44 ± 19%, n = 4) than in varieties located 200 m or more away (14 ± 6%, n = 11; t = 2.95, d.f. = 14, P < 0.01; t-test).

Discussion

This series of orchard experiments explored the potential of synthetic aggregation pheromones in suppressing Carpophilus spp. populations during fruit ripening in stone fruit orchards. Two strategies were investigated: perimeter-based mass trapping and attract and kill population diversion. Both strategies appeared to result in lower beetle populations in stone fruit blocks and minimal crop damage.

In an earlier study (James et al., 1996a) perimeter-based mass trapping (traps hung in perimeter trees) significantly reduced the incidence of Carpophilus spp. in ripe fruit in the centre of a 1-ha apricot orchard. However, there was almost 100% infestation by Carpophilus spp. in fruit on the trees in which the traps were hung. Consequently, in the current study the technique was modified so that suppression traps were situated 5-10 m from perimeter trees. Two experiments (1 and 3) were conducted in the same organic Mangrove Mountain orchard under 'high' (8000-43 000 beetles trapped weekly in suppression traps 1995) and 'low' (2000-4250 beetles trapped weekly 1996) Carpophilus spp. population pressure. Outcomes from both experiments were similar, with less than 2 beetles/trap/week captured in intrablock monitoring traps during harvest periods. Fruit damage in both experiments was less than 1%. This was remarkable considering the very large numbers of beetles trapped in suppression traps just 5 m from the fruit blocks.

Figure 4: Carpophilus spp. caught in 32 pheromone/coattractant-baited suppression traps (total 480 mg pheromone/fortnight) hung in four citrus trees, and in six funnel traps (Lucitraps) baited with ripe, damaged peaches in a nearby (130m) Golden Queen peach block (experiment 4).

Figure 5: Carpophilus spp. captured in pheromone/coattractant monitoring traps located greater than 200 m (n=9) and less than 200 m (n=10) from a concentrated source of pheromone/coattractant (total 600 mg pheromone/fortnight) (experiment 5).
Unexpectedly, beetle numbers also appeared to be suppressed in the peach (Sherman) block 15 m from the cordoned block, negating the original intention to use this block as a ‘control’. Furthermore, the lack of beetles and fruit damage in a nectarine block 250 m away, suggested an even greater zone of pheromone attractivity. By contrast, commercial stone fruit orchards in the Mangrove Mountain district were badly affected by Carpophilus spp. during September–November 1995 when experiment 1 was conducted. A significant number of beetles (27 trap/week) were caught in co-attractant-only traps in a commercial orchard 1 km away. Pheromone (500 μg septum) and co-attractant-baited monitoring traps in two other district orchards caught up to 300 beetles/trap/week during this period (James et al., 2000c). James et al. (1997) showed that mean pheromone (500 μg) monitoring trap catches > 10 beetles per week are indicative of populations likely to cause damage to ripening stone fruit.

A large zone of ‘pheromone influence’ was also indicated in experiment 2 where, in addition to protecting the cordoned block, the pheromone cordon also appeared to suppress Carpophilus spp. populations in fruit blocks 200 and 370 m away. However, a population 650 m from the cordoned block appeared to be unaffected.

The apparent large zone of Carpophilus spp. attraction radiating from a concentrated source of synthetic aggregation pheromones prompted the final two experiments where we examined the potential of diverting beetles away from ripening fruit. Experiment 4, although conducted under low Carpophilus spp. pressure, suggested that a high concentration, pinpoint source of pheromone could attract beetles out of and away from ripening stone fruit. Experiment 5 was conducted under high Carpophilus spp. pressure in a commercial Mangrove Mountain orchard with fruit damage occurring at the outset. A concentrated source of pheromone and co-attractant in an open area in the centre of the orchard acted as an attractive ‘beacon’ for Carpophilus spp. within the orchard and perhaps beyond. However, fruit damage assessment and monitoring trap data collected throughout the orchard indicated that larger populations of Carpophilus spp. occurred within 200 m of the pheromone source, compared to locations more distant. The failure of co-attractant-only traps to capture beetles during the first period of the experiment means we cannot be certain that this pattern of population density did not exist prior to deployment of the pheromone source. However, a naturally uneven population density of Carpophilus spp. in this orchard would appear to be unlikely, given the even distribution of food and shelter resources. Many of the fruit varieties in the outer zone of trapping are known to be highly susceptible to Carpophilus spp. damage and the grower expressed surprise at their relative freedom from beetle damage in 1998/99. For example, two varieties located 200–250 m from the pheromone source that suffered 80–100% fruit loss in 1997/98 (Ruby Diamond, Summer Bright) escaped with less than 5% damage in 1998/99.

Possible explanations for larger populations of beetles occurring close to the pheromone source include insufficient close-range stimuli for beetles to enter the drums, ineffective poisoning of attracted beetles, low quality and/or overcrowded food resources in the drums and possible repellency of tau-fluvinate to Carpophilus spp. Beetles attracted to the ‘pheromone zone’ may be unable to navigate successfully towards the insecticide-treated fruit drums, similar to the situation reported by James et al. (1996a), where beetles were attracted to trees with traps but did not necessarily enter the traps. Once Carpophilus spp. enter an atmosphere with a defined level of pheromone, point source searching may be reduced or terminated. In addition, approximately 30% of the Carpophilus spp. population comprised C. gaveni and C. marginellus, which are likely to be less attracted to a pinpoint C. davidsoni pheromone source than C. davidsoni. A comparable (but less pinpointed) pheromone source than that used in experiment 5 was used in cordon experiments 1 and 2, without evidence of increasing nearby Carpophilus spp. populations and damage. However, the major difference between the cordon experiments and experiment 5 was that traps were not used in the latter experiment. It is possible that the 10–14 day insecticide treatment of fruit drums in experiment 5 was insufficient to continuously kill incoming beetles during the experiment. The rapid breakdown of fruit in the drums, and the high numbers of beetles and ferment flies (Drosophila spp.) present, may have presented a suboptimal food resource for incoming Carpophilus spp. In addition, preliminary laboratory bioassays with the synthetic pyrethroid insecticide used in experiment 5 (tau-fluvinate) (D. G. James and B. Vogele, unpublished observation), indicate some repellency to Carpophilus spp.

These experiments help to further define possible pheromone-based strategies for population suppression of Carpophilus spp. in stone fruit orchards. Perimeter-based mass trapping, as indicated by James et al. (1996a) and confirmed here, can be an effective way of keeping Carpophilus spp. populations below damaging levels during fruit ripening and harvest. However, all experiments to date have used pheromone/co-attractant-baited traps positioned at 3–5 m intervals around the protected block. Clearly, this sort of trap/pheromone density would not be practical and/or economic with large commercial stone fruit blocks and orchards. We do not know how far apart pheromone traps can be placed before intrablock populations of Carpophilus spp. exceed damaging levels. It is possible that traps could be placed 20 m or more apart without sacrificing control and this clearly needs to be investigated.

Using concentrated pheromone sources to attract Carpophilus spp. beetles out of stone fruit blocks prior to fruit ripening and to divert incoming beetles away from these blocks, may be the most practical use of pheromones for suppressing Carpophilus spp. populations. Deployment of a concentrated pheromone source (600–800 mg/fortnight) at a location away from the fruit to be protected, commencing a few weeks prior to fruit ripening and continuing until harvest is completed, has the potential to minimize Carpophilus spp. populations and fruit damage. Further research should investigate whether the use of pheromone/co-attractant/insecticide point sources without traps inevitably results in an increased beetle population in the immediate vicinity as occurred in experiment 5. Carpophilus spp. are readily mass trapped in any kind of funnel trap (James et al., 1996b) and trapping at a point source may present less risk to nearby fruit.

The effective attraction range of synthetic Carpophilus spp. pheromones has not been reported, although unpublished studies (D. G. James, in preparation) indicate beetles can orientate from at least 500 m to pheromone traps baited with 5 mg of pheromone.
and co-attractant. Evidence presented in this study also indicates that attraction may occur from 200 to 400 m.

Definitive information on the effective attraction range of *Carpophilus* spp. pheromones is clearly needed before good recommendations can be given concerning the location and number of concentrated pheromone sources necessary to protect ripening stone fruit.

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**References**


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