EFFECT OF CARDBOARD SHELTER TRAPS ON PREDATION OF DIASPIDID SCALE INSECTS BY EUROPEAN EARWIGS, *FORFICULA AURICULARIA*, IN KIWIFRUIT

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ABSTRACT

European earwigs, *Forficula auricularia* L., are important predators of diaspidid scale insects in New Zealand kiwifruit. As European earwigs readily hide during the day in shelter traps made of corrugated cardboard strips rolled into cylinders, it may be possible to manipulate the level of scale predation. The effect of trapping duration on aggregation of earwigs and whether the addition of shelter traps to kiwifruit vine canopies led to increased numbers of earwigs and predation of scale insects were investigated. More earwigs were found in cardboard shelter traps exposed for up to 8 weeks than shorter periods. However, shelter traps were not associated with increased numbers of earwigs in vine canopies or with increased predation of scale insects. Predation of scale insects was 73-82% and on individual canes depended on the initial density of scale. Further study is needed to realise the potential of earwigs as predators of scale insects and other pests.

Keywords: predation, diaspidid scale insects, kiwifruit, earwigs, shelter.

INTRODUCTION

The limited availability of new and selective insecticides and difficulties in importing new biological control agents into New Zealand means that existing insecticides and biological control need to be carefully managed to optimise pest management. Indigenous or established exotic generalist predators can suppress pests in a wide range of crops and have the advantage of persistence in the absence of pests and opportunistic feeding habits to exploit pest outbreaks (Symondson 2002). European earwigs, *Forficula auricularia* L., are generalist omnivores and are considered to be important natural enemies in apples under IFP and organic regimes in Europe, North America and Australia (Carroll & Hoyt 1984a; Mueller et al. 1988; Nicholas et al. 2005). European earwigs have recently been identified as predators of diaspidid scale insects in New Zealand kiwifruit (Hill et al. 2005). Scale insects are the most important quarantine pests of kiwifruit exported to key Asian markets. Up to 40% of scale insects are eaten prior to harvest in autumn and this is mainly attributed to earwigs, which occur in the canopy of kiwifruit during summer and autumn (D.P. Logan & B.J. Maher, unpubl. data).

Diaspidid scale insects are managed in kiwifruit orchards using a combination of organophosphate and mineral oil sprays supplemented by winter pruning to eliminate scale insect refugia in branch stubs and junctions. The most effective insecticides for scale control, diazinon and chlorpyrifos-based products, are not used by organic producers, but scale insects do not occur at significantly higher levels in organic than conventionally-managed kiwifruit (M.G. Hill, unpubl. data). Biological control by earwigs may contribute to suppressing scale insect infestation in organic blocks, but not in conventionally-managed blocks. This is at least partly because diazinon residues are highly toxic to earwigs and probably substantially reduce earwig populations in conventionally-managed kiwifruit (Maher et al. 2006). As European earwigs readily hide during the day in artificial shelter (Lamb & Wellington 1974; Lamb 1975; Phillips 1981), manipulating the distribution of shelter in vines may influence local levels of earwigs and provide a means of managing scale insect predation. Carroll & Hoyt (1984b) released European earwigs in an apple orchard in Washington, USA, after adding artificial shelter to trees and straw to the ground. Numbers of aphids on trees with shelter were reduced by a factor of 40 relative to control trees.

The objective of the work reported here was to determine whether providing artificial shelter in vine canopies would enhance local populations of earwigs and predation of scale insects by earwigs.

METHODS

General methods

All experiments relied on a standard form of artificial shelter trap for monitoring numbers of earwigs. The shelter traps were made of strips of corrugated cardboard (100 mm wide, 850 mm long) rolled into cylinders. Similar or identical traps have been used in studies of European earwigs elsewhere (Phillips 1981; Helsen et al. 1998; Burnip et al. 2002). The shelter traps were secured in the canopy of kiwifruit vines by means of a large wire staple, and protected from the weather by a plastic bag or an inverted waxed-paper milkshake container. Replicate observations were on individual vines, and treatments were assigned randomly to vines. Statistical analysis was completed in GenStat 9.1 or in R (R Development Core Team 2006). Significance for all statistical tests was $P<0.05$.

Occupation of shelter traps

The effect of trapping duration on earwig occupation of shelter traps was studied in an organically-managed block of *Actinidia chinensis* cv. Hort16A kiwifruit. Treatments were eight trapping periods (1, 2, 3, 4, 5, 6, 7 and 8 weeks, starting from 27 November 2006), with ten vines per treatment and 80 vines in total. One shelter trap was secured in the canopy of each vine. Each week the 10 traps were removed, and earwigs in the traps were counted and released at the base of the same vine they were trapped in. The starting date for the study was based on phenology data for shelter traps left in vines for 1-week periods that indicated that most earwigs were present in the kiwifruit canopy in December and numbers declined steadily after early January (D.P. Logan, unpubl. data). At the end of week 7 (15 January 2007), new traps were placed in vines used for treatment 1 (1 week duration) and emptied after 1 week coincident with counts for treatment 8 (8 weeks duration).

As data had a strong positive skew and means were correlated with the standard deviation, counts were transformed by $\log(x + 0.5)$ before analysis by one-way analysis of variance. Histograms and scatter plots of the residuals were examined to ensure that deviations were normally distributed and evenly spread across groups. Counts for traps exposed for 8 weeks from November and traps exposed for 1 week in January were compared by Mann-Whitney U test.

Shelter traps and earwig abundance in vines

The effect of shelter traps on the abundance of earwigs was determined by counting adults in the canopy of 30 vines in an organically-managed block of Hort16A kiwifruit. The area of each vine sampled was standardised by counting earwigs in eight non-overlapping 0.25 m^2 quadrats located haphazardly along the main leader of each vine. Four shelter traps were secured to the top of the vine leader on 23 January 2007, and were at approximately equal distances from each other. Within each quadrat, pruning stubs and dead leaves ('natural shelter') were removed from the vine leader and adjacent canes, and destructively searched for earwigs on 28 February 2007. As an indirect measure of earwig presence, ten clear polycarbonate tubes (5 ml) each with 1.2 g of general purpose insect diet (Singh 1983) were secured to the top of the leaders of all 30 vines on 20 February 2007. Clear tubes were selected to indicate feeding only, since

Suckling et al. (2006) reported earwigs readily sheltered in covered diet tubes, but rarely sheltered in clear tubes. After 1 week, and 1 day prior to canopy quadrat sampling, the number of tubes with diet-coloured frass consistent with feeding by earwigs was recorded for each vine.

Counts of earwigs found in shelter traps and in natural shelter were first combined to provide an estimate of the total number of earwigs in the canopy of vines with traps. Numbers of earwigs for each vine were then square root transformed to remove a right skew in data before treatment means were compared by two-sample t-test. Proportions of tubes with frass were transformed by arcsine and means were compared for vines with and without shelter traps by a two-sample t-test.

Effect of shelter on predation of scale insects

The effect of shelter traps on predation rates of scale insects was determined for 30 mature female vines in an unsprayed block of *Actinidia deliciosa* cv. Hayward kiwifruit. Vines were randomly allocated to one of two treatments, 'with shelter traps' and 'without shelter traps'. Four shelter traps were placed equidistantly along the main leader of each of the 15 vines allocated to 'shelter trap' treatment on 2 November 2006. Canes extending from leaders were examined for adult scale insects on 26 October 2006. Single or groups of 2-10 scale insects were circled by permanent marker pen on four separate canes. Marked scale insects were within an area of approximately 100 mm of cane, and were often at the junction of two canes. Each single or group of marked scale insects was assumed to be independent of others as earwigs had a choice of at least 20 secondary branches and canes to search when travelling along the main leader. Marked scale insects were checked for predation after 1 week (2 November 2006) and then at 2-week intervals until the last count on 24 January 2007. Scale insects were recorded as predated if part of or the whole wax cap was missing and the insect gone.

Predation appeared to be density-dependent, and data for vines with and without shelter traps were grouped according to the number of mature scale initially marked. Four groupings were used: 1, 2 or 3, 4 or 5, and 6-10. As all depletion of scale numbers was recorded as due to predation, censoring did not occur. Kaplan-Meier estimates of the survivor curves were compared using the non-parametric approximation to the chi-square distribution.

RESULTS

Occupation of shelter traps

Trapping duration from late November had an effect on the number of earwigs found in shelter traps (P=0.011), with a trend for more earwigs to be found in traps left for the longest periods (Fig. 1). Traps that were left in the canopy for 8 continuous weeks from late November had more earwigs (mean/trap = 5.5) than traps placed in the canopy for 1 week in mid-January (mean/trap = 0.8) (P=0.017).

Shelter traps and earwig abundance in vines

There was no difference in the proportion of diet tubes with earwig frass pellets in vines with (back-transformed mean = 0.367) and without (back-transformed mean = 0.333) shelter traps (P>0.05). The number of earwigs found in natural shelter (hollow pruning stubs, bark and dry leaves) in vines without shelter traps did not differ from combined trap and natural shelter counts for vines with shelter traps (P>0.05). For the 15 vines with shelter traps, there was no correlation between counts of earwigs in traps and those found in natural shelter in the same vine (P>0.05) (Fig. 2).

Effect of shelter on predation of scale insects

Predation of marked scale insects on 24 January 2007 was 73% (initial total = 168 scale insects) in vines without shelter traps and 82% (initial total = 162 scale insects) on vines with shelter traps. There was no difference between Kaplan-Meier estimates of survival between scale insects on vines with and without shelter traps, irrespective of initial cluster size (P>0.05) (Fig. 3).

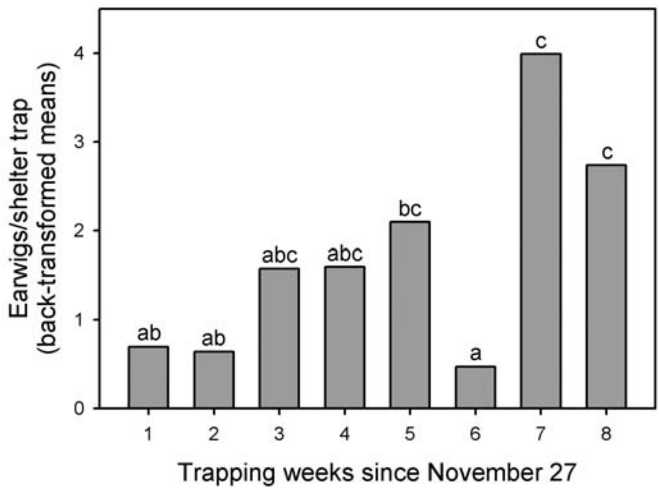

FIGURE 1: Number of earwigs in cardboard shelter traps left in the canopy of kiwifruit vines for 1-8 weeks. The same letters on the top of columns indicate groups within which there is no significant difference (LSD test at P<0.05).

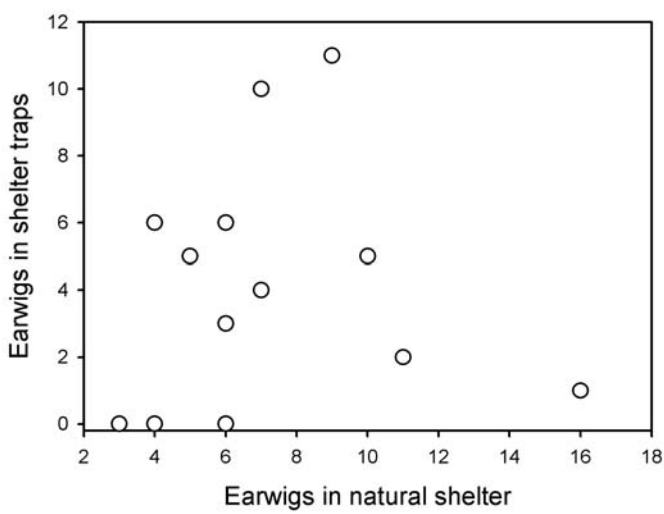

FIGURE 2: Scatter plot of the number of earwigs found in four cardboard shelter traps and in natural shelter (hollow pruning stubs, bark and dry leaves) in the same vine.

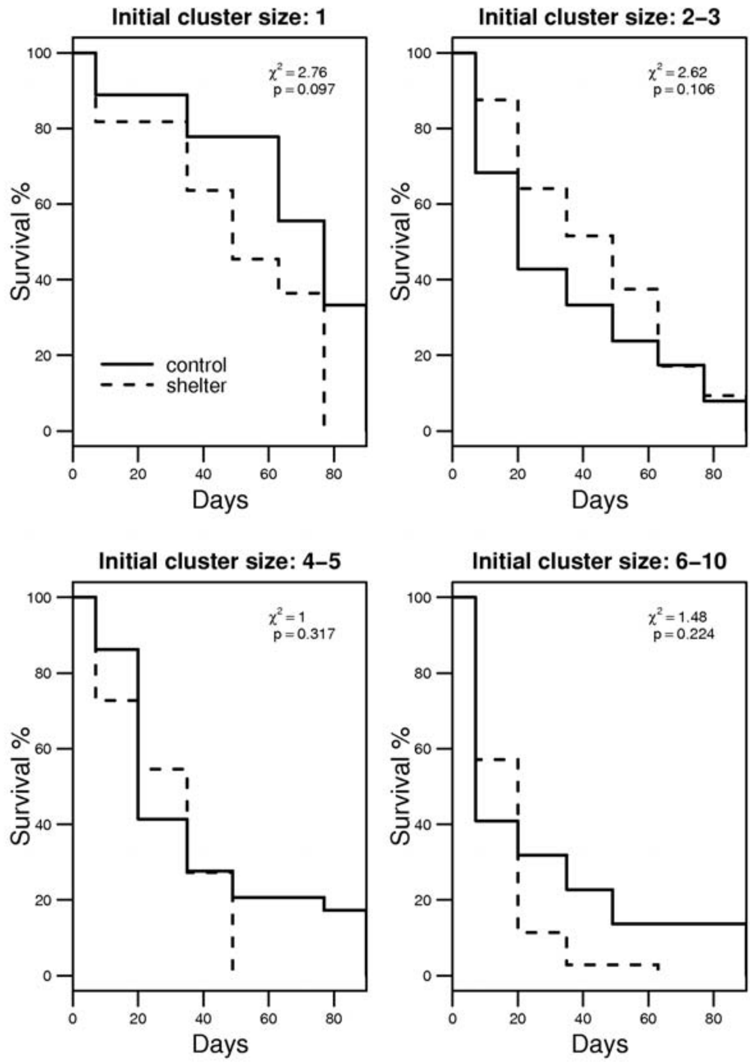

FIGURE 3: Kaplan-Meier survival curves for marked scale insects in vines with and without cardboard shelter traps. Scale insects were grouped according to initial density.

DISCUSSION

The longer that earwig shelter traps remained in the canopy of kiwifruit vines, the more likely they were to contain higher numbers of earwigs. Similarly, Phillips (1981) found occupation by European earwigs of shelter traps increased over a 1-14 day period. The pattern of increasing trap occupation is unlikely to be an artefact of an increasing general population of earwigs. Studies of earwig phenology in groundcover and in the canopy of kiwifruit using shelter traps with 1-week catch periods indicated that populations reach a peak around mid-December and are declining in January (D.P. Logan, unpubl. data). The significant dip in trap catch at 6 weeks is without an explanation. Sprays (Bt) were applied to vines during the day on 7 December 2006 (during the second week of trapping) and on 2 January 2007, six days prior to trap counts at six weeks. As shelter traps were securely fastened to vine leaders and there was no evidence they were disturbed during the trapping period, it is unlikely that spray application was responsible for the low catch.

Increased use of artificial shelter over time by European earwigs may be related to accumulating deposits of male cuticular lipids that contain an aggregation compound (Walker et al. 1993). Lamb (1975) found that European earwigs preferred to shelter in traps that already had resident earwigs over traps that were empty and this may support the role of an aggregation pheromone. Use of artificial shelter is also related to the availability of food in the near vicinity. Lamb (1975) found that earwigs did not return to shelter when the local food supplies were exhausted. In kiwifruit, supplementary feeding of earwigs with pollen led to significant local increases in earwigs in shelter traps relative to adjacent vines (D.P. Logan, unpubl. data), but replication is needed to confirm the result. Occupation of artificial shelter may be reduced by the ready availability of adjacent natural shelter (Lamb 1975; Burnip et al. 2002). Trap catches of European earwigs were higher in sparse groundcover than in dense groundcover (Lamb 1975), and higher in herbicide-treated groundcover than in a groundcover of pea straw mulch (Burnip et al. 2002). In the present study, it is not clear that natural shelter was competing with cardboard shelter traps within the same vine canopy as there was no association between counts of earwigs in natural shelter and shelter traps. This may indicate that within a vine, earwigs do not have a preference for natural shelter over cardboard shelter traps. Further, it raises the question of whether individual vines are the most appropriate spatial unit for studies of earwigs in kiwifruit blocks.

A trapping duration effect may indicate increases of earwig populations in individual kiwifruit vines and this is potentially useful for manipulating biological control. However, in this study cardboard shelter traps did not influence the number of earwigs, their level of feeding activity, or the rate of predation of scale insects within individual kiwifruit vine canopies. Vines provide many natural shelter sites for earwigs in hollow pruning stubs, dead leaves, and to lesser extent, loose bark, and it is concluded that natural shelter in canopies is probably not limiting for earwigs in mature vines in mid-summer. European earwigs can shelter in the groundcover of orchards (Phillips 1981; Burnip et al. 2002), but we discounted groundcover as a significant source of earwigs for vine canopies because relatively few adult earwigs were found in searches and shelter traps at ground level in a kiwifruit orchard (D.P. Logan, unpubl. data).

Manipulative studies in which European earwigs are excluded from fruit-trees by sticky-bands indicate they may suppress pests by 50% or more even when they occur at densities as low as five per tree (Mueller et al. 1988; Solomon et al. 2000; Nicholas et al. 2005). However, studies of the effects of adding artificial shelter to fruit trees have met with mixed success (Carroll & Hoyt 1984b; Carroll et al. 1985; Solomon et al. 2000). In kiwifruit at least it appears that there is sufficient natural shelter for earwigs, and additional artificial shelter for earwig encouragement is redundant. Further studies with artificial shelter as a method of monitoring populations are warranted, as are studies that focus on means other than use of artificial shelter to conserve and enhance populations of earwigs within a kiwifruit block. Supplementary food, increasing groundcover to provide greater arthropod prey abundance and diversity (e.g. Altieri & Letourneau 1982; Rieux et al. 1999) and avoiding the application of insecticides that are toxic to earwigs may contribute significantly to earwig conservation. Density-dependent predation of scale insects is also an area for further study and may limit the contribution of earwigs in commercial orchards where scale populations are typically low.

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