A sustainable approach to control top fruit pests

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Left - Earwigs are important predators of orchard pests. Photo: iStock;
Right - Female earwig tending eggs in underground nest. Photo: Dr Michelle Fountain, NIAB EMR

European earwigs are important predators of orchard pests, they are capable of keeping the infestation degree of several orchard pests, like scale insects (Karsemeijer, 1973; McLeod and Chant, 1952), the apple aphid (Carroll and Hoyt, 1984), codling moth (Glenn, 1977) and spider mites (Phillips, 1981) below economic threshold levels.

The earwig, *Forficula auricularia*, is a generalist feeder that survives on plant material, mosses or fungi, but, given the chance, preferentially consumes small arthropods (Phillips 1981). The common European earwig is a brown insect, it is up to 13-15 mm long and has a pair of distinctive pincers or forceps on their rear end. Earwigs hide in sheltered places during the day and emerge after dark to feed. On fruit trees earwigs can give good control of fruit aphids and do not cause damage to the trees or fruit. Providing shelters such as bioactive refuges stuffed with food volatiles in trees can help increase numbers.

Males and females form pairs in autumn and hibernate in underground nests. Earwigs are unusual among insects in that the female exhibits maternal care. When she is ready to lay her eggs, she drives the male out of the underground nest. She lays around 50 eggs in winter. She cleans and moves her eggs around in the nest so they don't get mouldy and guards them from other earwigs. She also cares for and feeds the newly hatched young in the nest until they can fend for themselves. The nymphs look like smaller versions of the adult insect. Females abandon the nests when nymphs become second instars; these nymphs will disperse shortly thereafter and move to weeds, shrubs or trees. Especially around early summer (end of June, early July) an abundance of late instar earwigs is present in orchard trees.

The best documented predatory effect of earwigs is that toward the woolly apple aphid *Eriosoma lanigerum*, a major pest in apple orchards with integrated or organic pest management. Studies in both Holland (Mueller et al., 1988) and in Australia (Nicholas et al. ,2005) demonstrated a direct effect of earwig exclusion on woolly apple aphid proliferation, and a negative correlation between degree of aphid infestation and the number of earwigs present on the trees. In relation to an abundant pear pest *Cacopsylla pyri*, a semi-field test showed consumption of large numbers of eggs by earwigs confined to sleeves on pear branches (Lenfant et al.,1994).

Woolly aphid (*Eriosoma lanigerum*) is an important pest of apples causing hypertrophic gall formation on the roots and limbs of the tree (Brown et al., 1991). The galls restrict sap flow and frequently

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rupture providing further feeding sites for woolly aphid and allow the invasion of fungal diseases (Childs, 1929; Weber and Brown, 1988). Heavy infestations can reduce tree growth and vitality, destroy buds, reduce cropping, and lower fruit quality.

Mueller et al., 1988, compared woolly apply aphid predation by the common earwig, *Forficula auricularia*, and other predators in high, intermediate and low earwig density plots of mature apple trees at an experimental orchard in the Netherlands. Aphid colonies were discovered and exterminated primarily by earwigs much more rapidly in the high and intermediate earwig density plots than in the low density plots. Where earwigs were excluded from trees by glue bands around the trunks, woolly apple aphids infested 30–35% of new growth shoots whereas less than 10% of the shoots were infested where earwigs were relatively abundant.

However, several other factors including the availability of alternate prey, earwig developmental phenology and weather probably influenced the outcome of the predation experiments. Nevertheless, it was found earwigs play an important role in suppressing woolly apple aphid populations and are potentially important naturally occurring biological control agents for this pest.

The European earwig *Forficula auricularia*, which is widespread in Australian top fruit orchards, can consume up to 106 aphids per day (McLeod and Chant, 1952; Asante, 1995). Woolly aphid has several natural enemies in Australia, including earwigs, lacewings, ladybirds and hover flies. Earwigs have, by association, been shown to play an important part in controlling woolly aphid in the absence of broad-spectrum insecticides (Anon, 1969; Ravenberg, 1981; Stap et al., 1987; Mueller et al., 1988).

Two techniques, namely mating disruption and the insect growth regulator fenoxycarb, are now firmly established in Australian apple orchards as viable methods of controlling codling moth (*Cydia pomonella*), which is the key pest of apples in mainland Eastern Australia (Thwaite, 1997). These techniques are the basis of current commercial IPM programs in Australia (Thwaite, 1997).

Codling moth mating disruption is highly species specific (Rumbo et al., 1993) with no direct effect on woolly aphid or its natural enemies. In conventional pesticide programs, controlling codling moth with azinphos-methyl requires 6–8 applications during the season (Thwaite et al., 1995) and these sprays affect many secondary pests and their natural enemies. Adopting an IPM strategy, thereby reducing the use of broad-spectrum insecticides, is likely to have indirect effects on the orchard's other inhabitants, including the woolly aphid and its natural enemies (Nicholas et al., 1999).

Nicholas et al. 2005 had conducted a study to assess the abundance of woolly aphid in IPM programs (i.e., in the absence of broad-spectrum insecticides) and investigated the potential of natural enemies including earwig to suppress the pest population. In a field study they found woolly aphid infestations in the Azinphos-methyl and Mating Disruption (AMD) blocks remained significantly higher than in the Mating Disruption (MD) and Fenoxycarb together with Mating Disruption (FMD) treatments. Infestation remained low in the MD and FMD treatments throughout the season. There was no significant difference in infestation between the MD and FMD treatments in either season.

Ladybird and hoverfly larvae were occasionally observed feeding on woolly aphid during the monitoring program. The only predators of woolly aphid found occupying the artificial shelters were European earwig *Forficula auricularia*. Trees fitted with adhesive exclusion bands were found to have significantly greater infestations of woolly aphid than unbanded trees when monitoring ceased. In the MD and FMD treatments there was a high negative correlation between the mean number of earwigs / trees in the artificial shelters and the mean woolly aphid seasonal infestation rating in all cultivars.

The significantly lower levels of infestation in the MD and FMD treatments in the 1995/1996 and 1996/1997 seasons, compared with that in the AMD treatment, shows that under the conditions of this trial, the abundance of woolly aphid in IPM programs was very low. Any infestation rated >1 would not be acceptable to Australian growers. The level of infestation that occurred in the IPM treatments reported here (where no trees were rated 2), would probably not have been detected by most commercial growers, and therefore additional control measures would not have been considered necessary.

The woolly aphid infestation recorded in trees treated with azinphos-methyl (many of which were rated 4), and those fitted with predator exclusion bands (i.e., those with fewer natural enemies), would therefore not be tolerated by commercial growers.

The lack of significant differences in woolly aphid infestation between the MD and FMD treated blocks indicate that either the full season program of fenoxycarb did not negatively impact on the biological control of woolly aphid, or its effects were only short lived and natural enemies moved in from adjacent blocks. It also shows that the use of MD allows for the establishment of biological control agents.

The correlation between the level of woolly aphid and the number of earwigs in artificial shelters indicates the earwig as the principal predator and hence control agent. The reduced insecticide programs used in this IPM field trial would have allowed survival of other natural enemies, including *Aphelinus mali*, lacewings, ladybirds and hoverflies. All were known to occur at the trial site (Nicholas et al., 1999) and are likely to have had a complementary effect, further reducing the level of woolly aphid infestation in the orchard. However, the high level of woolly aphid in the trees fitted with predator exclusion bands indicates they were not, individually or collectively, capable of controlling woolly aphid in the absence of earwigs.

The polyphagous feeding habit of earwigs means that, although they prefer live prey, particularly aphids, their long-term survival in an orchard and hence their availability as a control agent is not wholly dependent on the presence of woolly aphid. This means that earwigs can be introduced and remain established in orchards in the absence of woolly aphid. Noppert et al. (1987) used a simple deterministic simulation model to determine that eight earwigs, searching randomly, could search the average apple tree for prey with 90% efficiency.

They calculated the earwig's predation rate at approximately 70 aphids/earwig/night and found that, even at the lowest predicted predation rate, earwigs could 'eliminate' woolly aphid. Counting earwigs →

Wignest earwig refuges in place in orchard trees. Photos: Professor Jerry Cross / Dr Michelle Fountain, NIAB EMR

in artificial shelters is a relative rather than absolute measure of abundance, which can vary through the season depending on factors such as the availability of alternative refuge sites and weather (Phillips, 1981).

However according to Nicholas et al's 2005 finding, that a seasonal mean of eight and five earwigs are required to eliminate woolly aphid from the Granny Smith and Jonathan trees respectively supports the findings of Noppert et al.,1987. The data suggest that to maintain effective control of woolly aphid in Red Delicious more earwigs would be required than were present in the orchard during the 1996 /1997 season. Earwigs effectively suppressed woolly aphid below the >1 rating in the cultivars Granny Smith and Jonathan during the 1997/1998 season, although not as effectively as in the previous season.

Earwigs are highly mobile and known to migrate considerable distances (up to 3 m/min) in search of food and shelter (Noppert et al., 1987). This suggests that they have the potential to colonize orchards quickly following the removal of broad-spectrum pesticides. The blocks used in this trial were relatively small and further investigation is required to assess migration of earwigs into larger orchards.

The lack of a significant difference in woolly aphid infestation between the blocks in the first year of the fenoxycarb program and those in their third year, together with the presence of earwigs early in the season, shows that earwigs not only migrated into the blocks quickly, but their populations were sufficient to provide a similar level of control.

Earwig impact on codling moth

Codling moth (*Cydia pomonella*) is a serious pest of apple. In Southern France, over 35 pesticide treatments are applied yearly in apple orchards, of which 8–15 are targeted against the codling moth (Sauphanor et al., 2009). Several of its natural enemies have been assessed and used in classical augmentative or conservation biological control strategies, including predators (Glen, 1977).

The egg stage is the most targeted to avoid damage being caused to the fruits. Both egg parasitism (Yu et al., 1984; Cossentine and Jensen, 2000; Pinto et al., 2002) and egg predation may contribute to this early-stage biological control. Predator activity can be very efficient, leading to the rapid disappearance of sentinel codling moth eggs (Glen, 1977). Among other arthropods, earwigs (*Forficula* spp) are particularly efficient predators in undisturbed habitats (MacLellan, 1962, 1972; Glen, 1975).

It is suspected that broad-spectrum insecticides would reduce the abundance and the diversity of natural enemies in treated orchards, and consequently, their contribution to pest control (Simon et al., 2007). An increased abundance of beneficial arthropods will translate into increased pest control, subject to their sustainable establishment in apple orchards.

Monteiro et al., 2013 conducted a study in France about codling moth in which earwig abundances in traps were taken as an indication of codling moth pressure and of predators foraging in the orchards. To assess predation and parasitism they placed codling moth sterilized egg laying cards (1cm × 2cm) containing 14.7 eggs in apple orchards, ten on a border row and the remaining 20 on two rows within the orchard. Each card was fixed on the lower side of a leaf at the outside of the canopy at a height of 1.7m. After three days of exposure to natural enemies, the cards were removed, and predation and parasitism were assessed.

The predation rates in the organic and conventional strategies, respectively scored 21.2% and 4.9% of the egg cards in June and 61.3% and 36.0% in August. Despite its high initial codling moth population and high earwig abundance, the abandoned orchard had a predation rate in the range observed for organic orchards. Analyses on predation rates in the managed orchards, indicate that predation rates were significantly higher in August than in June and depended on crop protection strategy.

Monteiro et al., 2013 also observed higher predation rates, in particular in August. Although they had no direct observation of predators, some assumptions can

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be made. Earwig *F. auricularia* and various species of *Miridae* and *Anthocoridae* have been observed predating on isolated sentinel *C. pomonella* eggs in England (Glen, 1977). The generalist predator earwig feeds on the eggs including their corium. This is also often mentioned for its regulatory effect against aphid and psyllids in orchards (Lenfant et al., 1994; Mueller et al., 1988). The sustained presence of both frass (not shown) and earwigs in band traps of our study orchards is thus a strong indication of the possible involvement of these insects in egg predation.

In, 2016 after three years robust field and laboratory studies, the Wignest earwig refuges system has been developed by a consortium including Russell IPM Ltd., NIAB EMR, University of Greenwich, Worldwide Fruit, Fruition and Agrovista UK Ltd, in an Innovate UK project. The Wignest is a small, robust and compact device which boosts numbers of earwigs. Earwigs have proven invaluable within pome fruit orchards. They prey upon and significantly reduce numbers of damaging pests, such as the wooly aphid, codling moth, pear sucker and spider mites.

Effect of food on earwig refuge

In our studies more earwigs were generally found in refuges where food was provided (inside or outside the refuge) in spring. There was less distinction in earwig numbers in refuges in summer and autumn. Many other beneficial arthropods were also found in refuges, including lacewings, ladybirds and spiders. Food boosts earwigs and provides alternative food sources when natural sources are low, especially in new orchards. The bioactive Wignest refuge is usually pre-recharged with food paste during manufacture.

Laboratory analyses of dried food remaining in the refuges demonstrated that food was being eaten by earwigs. Where earwigs were present in the refuges there was less food remaining whether provisioned inside or outside the refuge. More food was consumed if placed inside the refuge in the autumn. The effect of food on earwig number was evaluated in apple orchards. In a 2014 field trial at Monk Farm in Kent, it was evident that the addition of food increased the number of earwigs. There were clear differences observed in Broad-water Farm as well.

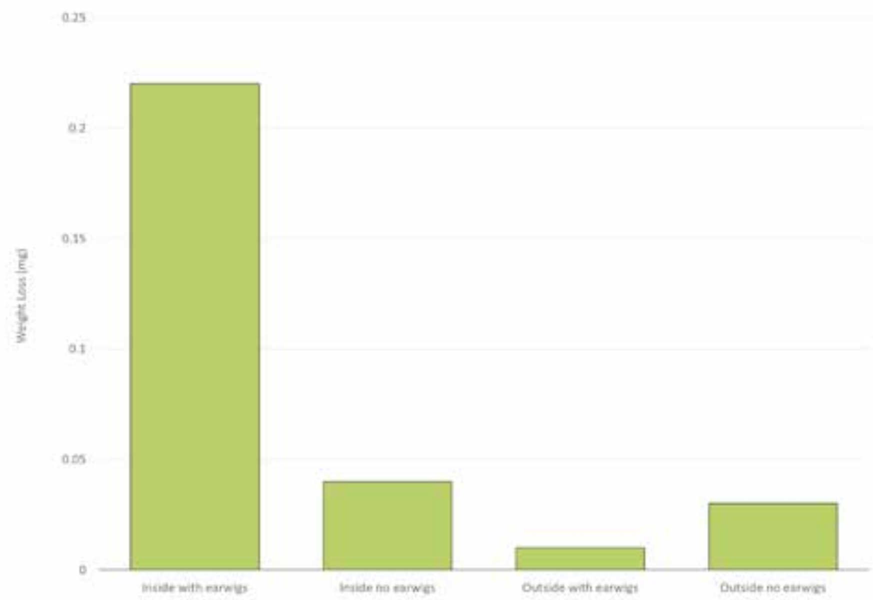

Figure 1. Earwig Laboratory Food Counsumption Study 2014, Food weight loss (mg).

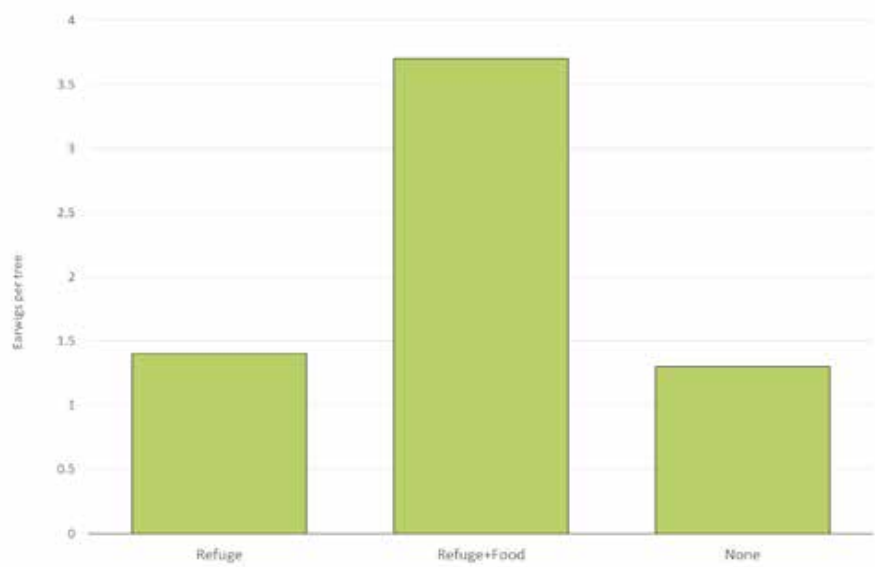

Figure 2. Mean number earwigs/pear tree. Broadwater Farm refuge evaluation 2014.

The above studies indicated that due to pesticide use and lack of shelter and food, earwigs are less successful in establishing in some pome fruit orchards. The earwig only produces one generation per year, so numbers can be diminished by insecticide use and soil disturbance if targeted during vulnerable stages of their life cycle. Providing shelter and food helps to establish a healthy population which will readily feed on pests.

We suggest placing one Wignest per tree at leaf bud-burst on a branch against the trunk of the tree within the lower tree canopy. The Wignest not only attracts earwigs, it provides shelter for a wide range of predatory species throughout the year. It will help various beneficial insect populations build up to tackle harmful pests in apple and pear orchards. The product Wignest will be available for UK top fruit growers from summer 2020. ■