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Biology and Management of European Earwig in Orchards and Vineyards

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Abstract

European earwig, *Forficula auricularia* L. (Dermaptera: Forficulidae), is an omnivore found in fruit orchards and vineyards worldwide. Earwigs are predators in many crop systems, but may be pests in others. To address uncertainty regarding the pest status of European earwig, we review its biology, effects in fruit agroecosystems, and management. Current evidence suggests that European earwigs generally have a net positive role in apple and pear orchards, where they consume pests and rarely damage fruit. European earwigs probably have a net negative role in stone fruits, which are soft and susceptible to earwig damage. The net positive or negative role of European earwig in citrus, grape, and kiwi is not clear because there is limited information on their ability to damage these fruits. Management of European earwig involves pesticide sprays or tillage to suppress vulnerable life stages, or inoculative releases to increase earwig populations. Greater appreciation of European earwigs as biological control agents may decrease insecticide use and improve pest suppression.

Key words: *Forficula auricularia*, monitoring, omnivory, pome fruit, stone fruit

European earwig, *Forficula auricularia* L. (Dermaptera: Forficulidae), is an omnivore native to Europe. It has spread to temperate and Mediterranean areas worldwide since the early 1900s (Crumb et al. 1941, Wirth et al. 1998, Quarrell et al. 2018). In fruit crop systems, European earwig can be both a pest or predator. This article provides an overview of European earwig biology, their positive and negative effects in fruit crop systems, and strategies to manage them as pests or predators.

Description

Eggs

European earwig eggs are found inside underground nests during winter and spring. Eggs are small (ca. 1 mm), yellowish white, and usually occur in masses of 30–60 per nest (Crumb et al. 1941, Lamb and Wellington 1975, Tourneur and Gingras 1992).

Nymphs

Excluding their pincer-like cerci (forceps), European earwig's four instars range from 4 to 11 mm long (Crumb et al. 1941). Nymphs have straight forceps (Fig. 1a), and instars can be identified their number of antennal segments: instars 1–4 have 8, 10, 11, and 12 segments, respectively (Crumb et al. 1941, Behura 1956).

Adults

Adult European earwigs are reddish-brown and 13–14 mm long (excluding forceps; Crumb et al. 1941). Females have straight forceps (Fig. 1b), whereas male forceps are curved (Fig. 1c).

Life Cycle and Phenology

Molecular evidence (Wirth et al. 1998; Guillet et al. 2000a,b; Quarrell et al. 2018) and laboratory mating experiments (Wirth et al. 1998) show that *F. auricularia* consists of two reproductively isolated clades designated A and B. Clade A occurs in cold-temperate climates of northeast North America, in Europe above 1,500 m, and in some Mediterranean areas of Europe. Clade B occurs in warm-temperate or Mediterranean climates of the southeast United States, western North America, Australasia, and Europe below 1,500 m (Wirth et al. 1998; Guillet et al. 2000a,b; Quarrell et al. 2018). No major biological differences have been reported for these clades except in reproductive characteristics. In the field and laboratory, clade A females usually produce one brood per year. Due to a longer period of fertility (Tourneur 2018), clade B females produce one to two broods, and sometimes three (Wirth et al. 1998, Guillet et al. 2000a,b, Tourneur 2018). An exception to this pattern is clade A populations from Mediterranean areas producing two broods per year (Wirth et al. 1998).

We present a general timeline of European earwig life history in Fig. 2 based on observations in cold climates. In late autumn, adults mate aboveground and then start a nesting phase by building a burrow (Crumb et al. 1941, Lamb and Wellington 1975, Lamb 1976a). During this phase, adults forage at night and return to the nest during the day (Lamb and Wellington 1975). After oviposition during winter, females drive males out of the nest and seal it (Lamb and Wellington 1974, Lamb 1976a, Tourneur 2018). The nesting phase continues in spring after eggs hatch (Fig. 3). Nymphs and mothers stay in nests during the day and forage at night; when not foraging, mothers defend the nest and tend to the nymphs (Lamb 1976a). In spring, the ground free-foraging phase begins when the first or second instars stop returning to nests and live on the ground (Lamb 1976b). European earwig nymphs later transition to a canopy phase and spend most of their time in plant canopies. This occurs during the fourth instar for clade A (Tourneur 2017) and the third instar for clade B (Lamb and Wellington 1974, Gobin et al. 2008, Dib et al. 2017, Tourneur 2017).

In Mediterranean climates, European earwig nymphs can be found on the ground from winter through spring, adults can be found in canopies through December (Romeu-Dalmau et al. 2012a, Lordan et al. 2015a, b), and some clade B females might be able to lay a third clutch of eggs (Tourneur 2018) due to warmer temperatures. Otherwise, phenology in Mediterranean climates is similar compared with cold climates (Fig. 2).

Feeding Behavior and Roles in Different Fruit Crops

European earwigs are nocturnal omnivores. Most of their foraging occurs during the first half of the night, after which they return to nests or hiding places, such as bark crevices or fruit clusters, and stay there during the day (Lamb 1975, He et al. 2008). Higher temperatures are associated with greater nightly movement between shelters, so might also be associated with greater foraging activity (Chant and McLeod 1952), whereas rain probably decreases foraging activity (He et al. 2008). European earwigs prey upon almost anything that is small or soft. Dissected European earwig guts are usually found

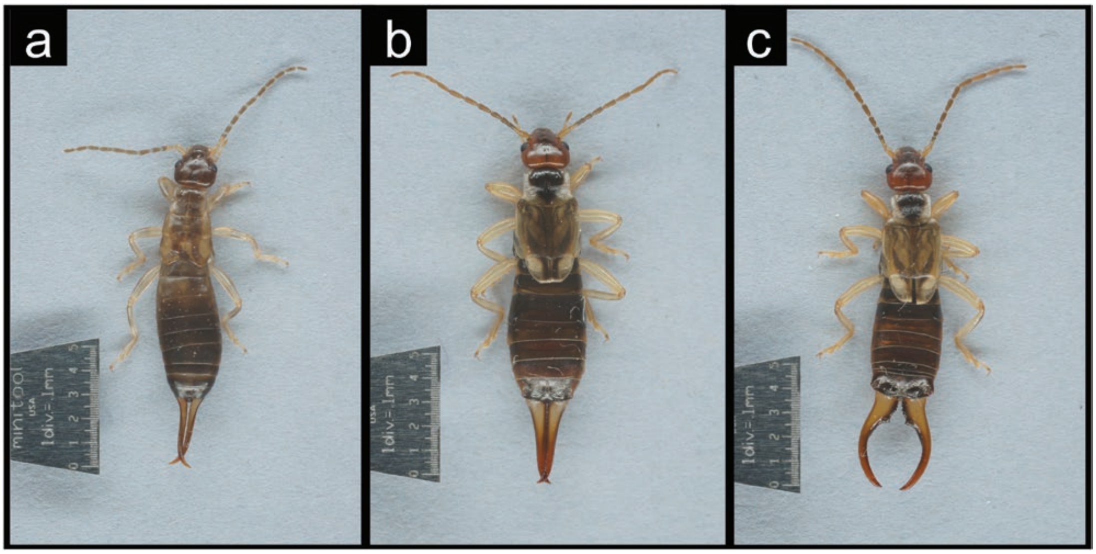

Fig. 1. European earwig nymph (a), adult female (b), and adult male (c).

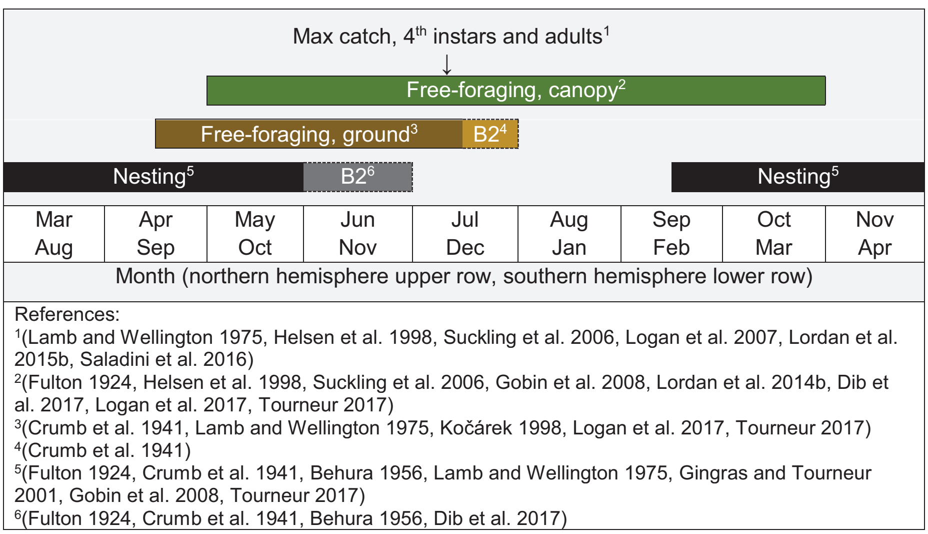

Fig. 2. Generalized phenology of European earwigs. B2 refers to second broods, when present.

with both plant and animal contents and commonly found foods include moss, grass, lichen, and aphids (Crumb et al. 1941).

Omnivory has significant implications for the role of European earwig as a biological control agent and pest. Relatively specialized natural enemies might starve or emigrate when abundance of their prey is low, whereas the omnivorous European earwig can survive on alternative foods. Combining earwigs with relatively specialized natural enemies such as coccinellids or parasitoids may strengthen biological control across the season, as earwigs can suppress low-density pest populations during periods when these other natural enemies are not present (Piñol et al. 2009a, Quarrell et al. 2017). The wide diet breadth of European earwig also means that they are predators of a variety of pests across crop types (Crumb et al. 1941, Sunderland and Vickerman 1980, Sunderland et al. 1987). On the other hand, European earwigs also have the potential to damage a variety of plants, including vegetables, grains, flowers, and fruits (Crumb et al. 1941, Murray et al. 2013).

Few studies address the net benefit or cost of European earwig in crop systems. A lack of information, combined with difficulty managers face in directly observing nocturnal European earwig behavior (Orpet et al. 2019), may lead to uncertainty on whether to manage earwigs as beneficial predators or harmful herbivores. Below, we review evidence on the potential for earwigs to suppress pests or cause damage in fruit crops.

Apple and Pear

European earwigs are generally beneficial in apple and pear orchards because they can suppress pests and probably do minimal damage to fruits. European earwigs have been reported to eat a variety of pests including apple leaf curling midge (*Dasineura mali* Kieffer) (Diptera: Cecidomyiidae) larvae (He et al. 2008), brown marmorated stink bug (*Halyomorpha halys* Stål) ((Hemiptera: Pentatomidae) eggs (Rice et al. 2014), codling moth (*Cydia pomonella* [L.]) (Lepidoptera: Tortricidae) eggs and larvae (Unruh et al. 2016), light-brown apple moth (*Epiphyas postvittana* [Walker]) (Lepidoptera: Tortricidae) eggs and larvae (Suckling et al. 2006, Frank et al. 2007), woolly apple aphid (*Eriosoma lanigerum* [Hausmann]) (Hemiptera: Aphididae) (Quarrell et al. 2017, Orpet et al. 2019), rosy apple aphid (*Dysaphis plantaginea* Passerini) (Hemiptera: Aphididae), green apple aphid (*Aphis pomi* DeGeer) (Hemiptera: Aphididae) (Carroll and Hoyt 1984a,b; Hagely and Allen 1990), oyster shell scale (*Lepidosaphes ulmi* [L.]) (Hemiptera: Diaspididae) (Karsemeijer 1973), and pear psylla (*Cacopsylla pyricola* [Förster]) (Hemiptera: Psyllidae) (Lenfant et al. 1994, Solomon et al. 1999). However, manipulative experimental evidence of earwigs suppressing pests in apple and pear orchards in the field only exists for woolly apple aphid (Mueller et al. 1988, Orpet et al. 2019), green apple aphids (Carroll and Hoyt 1984a, Carroll et al. 1985), and pear psylla (Solomon et al. 1999). In addition, nighttime video recording studies show European earwig

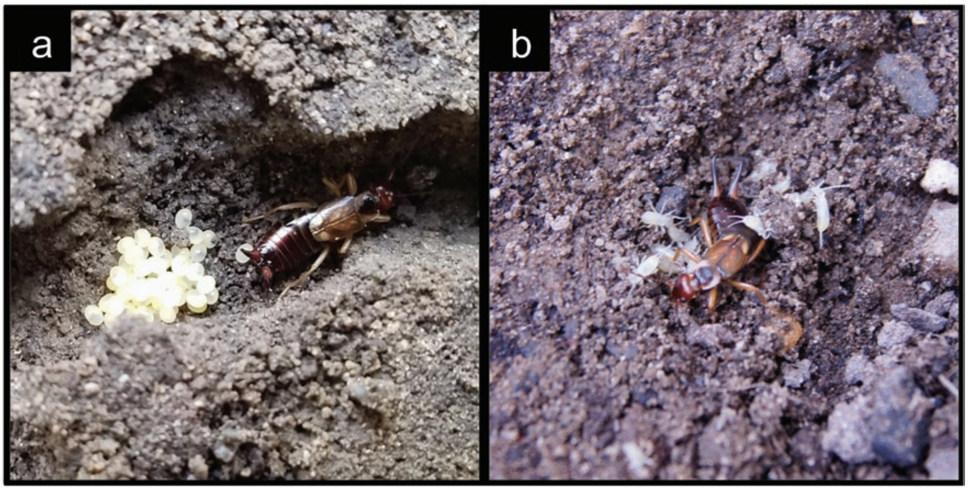

Fig. 3. European earwig nests with eggs (a) and nymphs (b) found underneath a concrete block on the grounds of Washington State University Tree Fruit Research and Extension Center on 23 April (photograph by L. Sherman) and 27 April 2019 (photograph by R. Orpet), respectively.

Fig. 4. Photographs of damaged apples: a small stem bowl split (a), stem bowl splits, which have been chewed on by an earwig (b, upper arrow) or where an earwig is sheltering (b, lower arrow), and (c) an example of earwig chewing damage after laboratory confinement with an apple.

consuming light-brown apple moth (Frank et al. 2007) and woolly apple aphid (Supp Video S1 [online only]) in the field.

European earwigs can produce holes in apples (Fig. 4c; Croxall et al. 1951, Glen 1975, Carroll et al. 1985, Phillips 1981, Solomon et al. 2000, Nicholas et al. 2004) and pears (Hilton et al. 1998) when artificially confined together with them and no alternative foods. Some observational studies suggest European earwigs damage apples in the field (Croxall et al. 1951, Phillips 1981). However, earwig damage to apple and pear fruits is difficult to assess in the field because earwig feeding damage can resemble other wound types or might occur at sites of existing previous injuries (Hilton et al. 1998, Nicholas et al. 2004). Experimental studies have found no evidence that European earwigs increase damage to apples in the field (Crumb et al. 1941, Nicholas et al. 2004, Orpet et al. 2019). Earwigs can be seen in splitting apples (Fig. 4a and b), but splitting occurs independently of insects (Opara 1993). Earwigs are also reported to feed on leaves, but this is thought to be of no economic concern to mature apple trees (Phillips 1981, Carroll and Hoyt 1984a, Carroll et al. 1985). However, feeding on leaves and stems of young trees can cause economic damage (Flint 2012). Overall, European earwigs appear to have limited ability to damage apple and pear fruits, and most evidence suggests European earwigs are generally beneficial in apple and pear because of their ability to suppress aphid and psyllid pests.

Stone Fruits

Stone fruits, such as apricot, peach, plum, and cherry, are vulnerable to earwig damage because of their soft flesh. European earwigs can chew shallow or tunnel-like holes in these fruits (e.g., Crumb et al. 1941, Santini and Caroli 1992, Alston and Tebeau 2011, Flint 2012, Allen 2013), feed on cherry stems (Allen 2013), and can cause damage to young trees by feeding on foliage and stems (Flint 2012). Reports of European earwigs damaging stone fruits are sporadic (Crumb et al. 1941, Saladini et al. 2016), but concern over earwig damage can be intense, with estimates of up to 40% losses in apricot and nectarine orchards in Italy (Santini and Caroli 1992). As on apples and pears, it is difficult to identify whether earwigs initiate damage or merely feed on existing wounds on stone fruits. However, unlike apples, exclusion of European earwigs from apricot or cherry trees results in less fruit damage (Allen 2013, Saladini et al. 2016, but see Lenfant and Sauphanor 1991). European earwigs may be effective predators of black cherry aphid (*Myzus cerasi* [Fabricius]) (Hemiptera: Aphididae) (Stutz and Entling 2011) and consume spotted wing drosophila (*Drosophila suzukii* [Matsumura]) (Diptera: Drosophilidae) in the field (Wolf et al. 2018), but studies on the economic benefits of earwigs in stone fruits have not been conducted. Overall, European earwig should generally be managed as a pest in stone fruit.

Citrus

European earwigs can prey upon California red scale (Romeu-Dalmau et al. 2012b) and aphids in citrus crops (Piñol et al. 2009b; Romeu-Dalmau et al. 2012a,c,d). European earwigs can damage citrus flowers, but this may not affect citrus yield (Romeu-Dalmau et al. 2012d). Given other reports that European earwigs are citrus pests (Kallsen 2006), future research is warranted to understand to what extent earwigs may be detrimental to citrus yields.

Grape

Earwigs have historically been considered beneficial in vineyards, but recent reports of earwig damage in European vineyards have spurred interest in managing them (Huth et al. 2009, 2011; Kehrli et al. 2012). At high densities, earwigs contaminate grapes with frass (Huth et al. 2009, Kehrli et al. 2012), feed on fruits, and possibly spread fungal pathogens (Huth et al. 2011). However, earwigs prey on lepidopteran pest eggs, larvae, and pupae (Buchholz and Schruft 1994, Frank et al. 2007). Therefore, as with citrus, grape vineyard managers should decide whether to suppress European earwigs on a case-by-case basis.

Kiwifruit

All studies investigating European earwigs in kiwifruit have focused on their role as a predator, and none mention earwig damage (Maher et al. 2006; Logan et al. 2007, 2011, 2017). Although European earwigs are predators of kiwifruit scale pests, no current experimental evidence has shown them to affect pest abundance in the field (Logan et al. 2007).

European Earwig Management

Strategies to manage earwigs depend on proper timing of tactics to target or avoid targeting vulnerable stages (Moerkens et al. 2011, 2012; Table 1). However, strategies to promote European earwigs may take years to have an effect because these insects have only one generation per year and low dispersal ability (Moerkens et al. 2010). Before adopting management strategies, populations should be assessed to determine whether changes in management practices are warranted.

Monitoring

Earwigs have an aggregation pheromone (Lordan et al. 2014b) and tend to form groups in tight spaces such as fruit clusters, tree bark, or debris. By exploiting this behavior, European earwigs are easily monitored using artificial shelters. For monitoring, place at least 10 rolled strips (7.6 × 35 cm) of corrugated cardboard in tree canopies during the summer for at least a week (Fig. 5). Earwigs can be shaken out of these shelters and counted. Maximum catch will occur once earwigs reach fourth instar (Helsen et al. 1998) (Fig. 2). Counts of 5–15 per shelter are associated with biological control of woolly apple aphid in apples (Nicholas et al. 2005, Quarrell et al. 2017, Orpet et al. 2019). However, shelter counts can be affected by the abundance of alternative hiding areas (Burnip et al. 2002), so further study on how to relate shelter counts to pest suppression or fruit damage under variable contexts, including different crops and tree sizes, is needed.

Pesticides

Table 2 lists pesticides shown to significantly decrease European earwig populations in the field. To manage European earwigs as pests or predators, pesticides sprayed on canopies should be timed to coincide with or avoid when earwigs are in their canopy phase (Fig. 2). Many pesticides have been tested against earwigs in the laboratory, but laboratory results on pesticide toxicity to earwigs often do not correspond to field results (Delate et al. 2008, Fountain and Harris 2015). Some pesticides found harmful in the laboratory may have little effect on European earwigs in the field if sprayed during the day, when earwigs are inactive. For example, nighttime sprays of spinosad suppress European earwigs more than daytime sprays (Huth et al. 2011). Other pesticides may appear safe in the laboratory mortality assays with adults, but can be highly toxic to nymphs (Sterk et al. 1999), yield variable results when tested using different methodologies (Peusens et al. 2010), or have considerable sublethal effects not measured by most assays (Malagnoux et al. 2015a).

Insecticidal baits can suppress earwigs while minimizing nontarget effects (Fulton 1923, Crumb et al. 1941, Bower 1992). Spinosad as a soil-applied bait formulation caused 90–100% European earwig mortality according to a laboratory study (Romeu-Dalmau et al.

Table 1. Summary of management tactics to conserve or suppress European earwigs

Management	Conserve earwigs	Suppress earwigs
Which fruits?	Apple (Mueller et al. 1988), pear (Solomon et al. 1999), kiwi (Logan et al. 2017), and possibly grape (Frank et al. 2007) and citrus (Romeu-Dalmau et al. 2012d).	Stone (Alston and Tebeau 2011), and possibly grape (Huth et al. 2011) and citrus (Romeu-Dalmau et al. 2012d).
Monitoring	Summer canopy shelters (Fig. 5). Interpretation: benefits level off at >4–14 earwigs per shelter; <1 earwig per shelter is too low for a considerable benefit (Mueller et al. 1988, Nicholas et al. 2005, Quarrell et al. 2017, Orpet et al. 2019).	Summer canopy shelters (Fig. 5). Interpretation: no clear quantitative relationship between earwig counts with fruit damage has yet been identified.
Pesticides	Avoid sprays listed in Table 2 during the earwig canopy phase.	Use sprays listed in Table 2 during the earwig canopy phase, or baits applied to the ground before the canopy phase. Spray after sunset during the first half of the night (Huth et al. 2011).
Soil disturbance and ground cover	Avoid tilling soil to >5 cm depth during the nesting phase (Sharley et al. 2008, Moerkens et al. 2012). Reduce herbicide and mowing frequency to maintain more groundcover or use mulch (Burnip et al. 2002, Suckling et al. 2006).	Till soil at >5 cm depth during the nesting phase (Sharley et al. 2008, Moerkens et al. 2012). Use herbicides or mowing to reduce groundcover, and do not mulch (Burnip et al. 2002, Suckling et al. 2006).
Collecting earwigs for inoculative or inundative releases	If <1 earwigs per shelter are found per tree, the area might benefit from earwig augmentation. Collect fourth-instar and adult earwigs during peak summer abundance (Fig. 2) from shelters placed in canopies at other locations and release 40 earwigs per tree at augmentation areas (Orpet et al. 2019).	Physical removal is not expected to greatly affect earwig abundance (Orpet et al. 2019).

Fig. 5. Example of a deployed cardboard shelter used for monitoring.

2012b, Malagnoux et al. 2015a). However, this bait formulation did not suppress European earwig in a citrus orchard (Romeu-Dalmau et al. 2012b), perhaps because earwigs were already in their free-foraging canopy phase when the bait was applied onto the ground (Fig. 2).

Fungicides and herbicides probably have minimal effects on earwigs (Hassan et al. 1994, Sterk et al. 1999, Nicholas and Thwaite 2003). However, fungicide use in the field has been correlated with lower earwig abundance (Malagnoux et al. 2015b), and fungicide–insecticide mixes may synergistically affect toxicity (Jansen et al. 2017).

Management on Orchard Floors

European earwig populations can be harmed by soil disturbance during the nesting phase. In one study, tilled plots had temporary European earwig population reduction (Sharley et al. 2008), whereas other studies showed minimal (Moerkens et al. 2012) or no effects of tillage (Huth et al. 2011). Refuges from tillage near trees where equipment cannot reach may allow earwigs to avoid harm. In addition, tillage is used for weed management mainly during the summer, outside of the nesting phase, mitigating its potential effects. For example, organic orchards extensively use tillage, but earwig abundance is often similar or greater in organic versus conventional orchards (Logan et al. 2011, Monteiro et al. 2013, Malagnoux et al. 2015b, Dib et al. 2016c).

Increased ground cover may benefit earwigs. Greater predation on light-brown apple moth larvae in tree canopies and more frass in earwig shelters were found in plots where straw was applied compared with plots treated with herbicides (Burnip et al. 2002, Suckling et al. 2006). In addition, mulched vineyard plots had more earwigs in pitfall traps than non-mulched plots (Addison et al. 2013). However, mowed or herbicide-treated apple and pear orchard plots had higher earwig shelter counts than mulched or less-mowed plots (Burnip et al. 2002, Horton et al. 2003). This may be because groundcover offered alternative hiding sites that decreased the efficiency of shelters. Overall, less soil disturbance and greater ground cover may promote European earwig populations.

Biological Control of European Earwigs

Populations of the parasitoid *Triarthria setipennis* (Fallen) (Diptera: Tachinidae) were released in western North America and New Zealand for biological control of European earwig during the early and middle 20th century (Fulton 1924, Kuhlmann 1991). As high as 47% of earwigs were found parasitized by *T. setipennis* in European apple orchards (Kuhlmann 1991), but parasitism rates in other studies are typically very low (Crumb et al. 1941; Moerkens et al. 2009, 2012; Alston and Tebeau 2011). New introductions of parasitoids might reduce European earwig populations in areas where the earwigs are considered invasive pests, such as the Falkland Islands (Maczey et al. 2016, 2019).

Entomopathogenic nematodes, including *Mermis* spp (Crumb et al. 1941) and *Steinernema carpocapsae* (Weiser) (Rhabditida: Steinernematidae) (Hodson et al. 2011, Lordan et al. 2014a), attack European earwigs, as do several species of fungi, including *Entomophthora forficulae* Giard (Entomophthorales: Entomophthoraceae), *Metarhizium anisopliae* (Metschnikoff) Sorokin (Hypocreales: Clavicipitaceae), and *Oospora destructor* (Metschnikoff) Delacroix (Erysiphales: Erysiphaceae) (Crumb et al. 1941). As with parasitoids, nematodes and fungi are usually

Table 2. Pesticides shown to significantly reduce European earwig abundance in the field compared with untreated controls or alternative spray programs

IRAC category and class	Pesticide	Reference(s)
1A, carbamate	Carbaryl	Bower et al. (1992), Romeu-Dalmau et al. (2012b)
1B, organophosphate	Chlorpyrifos	Bower et al. (1992), Bradely and Mayer (1995), Huth et al. (2011)
	Diazinon	Hilton et al. (1998), Maher et al. (2006)
3A, pyrethroid	Beta-cyfluthrin	Romeu-Dalmau et al. (2012b)
4A, neonicotinoid	Imidacloprid	Bradely and Mayer (1995), Huth et al. (2011)
	Thiacloprid	Vogt et al. (2008)
5, spinosyn	Spinosad	Vogt et al. (2008), Huth et al. (2011)
15, insect growth regulator	Novaluron	Beers et al. (2016)
	Diflubenzuron	Ravensberg (1981), Sauphanor et al. (1993)
22A, Na channel blocker	Indoxacarb	Vogt et al. (2008)
29, chordotonal organ modulator	Flonicamid	Vogt et al. (2008)
n/a, physical	Kaolin clay	Knight et al. (2001), Markó et al. (2008)

considered minor sources of earwig mortality (e.g., Crumb et al. 1941, Alston and Tebeau 2011, Moerkens et al. 2012), but they may be in important in some situations. For example, as high as 41.5% of earwigs used in a cage study with pear fruit were infected with mermithid nematodes in Oregon (Hilton et al. 1998).

Predators of European earwigs include ground beetles, birds, toads, and snakes (Crumb et al. 1941, Moerkens et al. 2009). Lamb (1975) suggested that adding artificial shelters to plots within a grassy field increased earwig abundance by providing refuge from birds. Addition of earwig shelters in kiwifruit, however, was not associated with an increase in earwig abundance, possibly because there was no shortage of natural hiding places (Logan et al. 2007). Overall, predators have an unclear role in affecting earwig abundance (Crumb et al. 1941), and more research is needed to determine how biological control of earwigs might be exploited by managers.

Environmental Factors

Climate and weather can influence European earwig population sizes. European earwigs do not thrive in arid environments except where there is a water source such as irrigation (Crumb et al. 1941, Zack et al. 2011, Quarrell et al. 2018, Hill et al. 2019). European earwigs also do not survive well where soil is consistently damp, such as shaded slopes (Behura 1956), and can experience high mortality in wet climates from fungi (Crumb et al. 1941). Irrigation strategies, therefore, may affect European earwig populations in orchards and vineyards, but this possibility has yet to be studied. European earwigs face high winter mortality (Gingras and Tourneur 2001, Moerkens et al. 2012). Their lethal lower temperature threshold is estimated at −3 to −5°C (Gingras and Tourneur 2001), and the length of time soil temperatures are below 8°C is correlated with lower winter survival (Moerkens et al. 2012). Therefore, lower European earwig abundance can be expected following harsher winters.

Landscape Factors

Outside of crop boundaries, European earwigs can be found in forest, hedgerow, and meadow habitats (Kočárek 1998). The presence of such habitat has been found to increase European earwig abundance in crops, but only at field edges (Bucher et al. 2010, Stutz and Entling 2011, Dib et al. 2017, Lefebvre et al. 2017). In contrast, a study in Europe showed lower European earwig abundance in apple orchards closer to woody habitat, which may have been due to bird predation or other factors (Happe et al. 2018). Overall, although manipulating habitat outside of crop boundaries may have effects on European earwig populations, this is unlikely to be a strong management tactic due to their low dispersal ability.

Inoculation or Inundation Releases of European Earwig

To improve biological control, fields could be inoculated or inundated with European earwigs. The goal of inoculation is to establish populations where future generations of a biological control agent will provide pest control, whereas the goal of inundation is for released individuals to provide immediate pest control (Eilenberg et al. 2001). Pest control provided by earwigs may level off when earwigs become highly abundant (Nicholas et al. 2005, Dib et al. 2016a). Therefore, inoculation can be a useful part of a long-term strategy to improve pest control in orchards that lack earwig populations, whereas inundation will probably not be a useful tactic where earwig populations are already high.

The main limitations of earwig releases are that they are time intensive and depend on finding a suitable area for mass collection. Orpet et al. (2019) inoculated a commercially managed orchard block originally lacking a European earwig population by releasing 46 earwigs per tree within sections of 39 trees across three rows (65 m^2). In 2017, an average of ca. 4.5 earwigs per shelter were found over the season in these sections, whereas almost none were found in control sections; these releases helped provide control of woolly apple aphids. This study showed earwig populations can be introduced into orchards to improve pest suppression, but highlights that earwig populations are not likely to spread rapidly from release areas (Moerkens et al. 2010). Earwig releases may be most effective at improving biological control in areas where monitoring has shown a low or absent population (<1 per shelter) and when inoculations are only needed at small spatial scales.

Conclusion

European earwigs are omnivores that can be beneficial predators or harmful pests in fruit and other crops. Although sometimes thought of as apple pests by managers (Orpet et al. 2019), substantial evidence indicates that European earwigs have a net positive role as predators in apple and pear orchards. However, European earwigs are probably pests in stone fruits, and their roles are unclear in citrus and grapes. Earwigs can be conserved or suppressed by timing management tactics to coincide with, or avoid coinciding with, vulnerable life stages (Table 1). Overall, our review shows that managing earwigs requires detailed knowledge about their phenology and roles in different contexts. This information can guide strategies to conserve or suppress earwig populations.

Supplementary Data

Supplementary data are available at *Journal of Integrated Pest Management* online.

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