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Nontarget effects of orchard pesticides on natural enemies: Lessons from the field and laboratory

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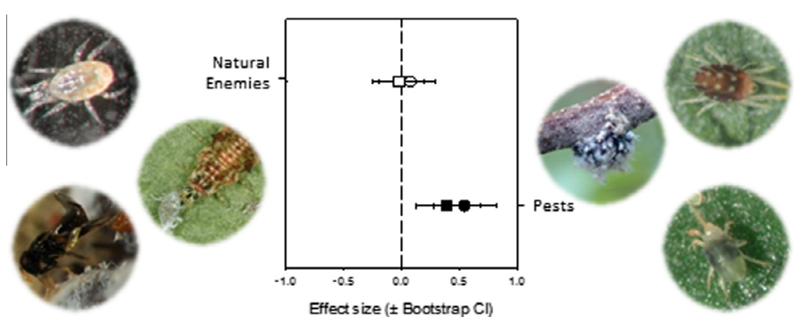
HIGHLIGHTS

- Laboratory studies predicted widespread negative effects on natural enemies.
- Relatively few negative effects on natural enemies were detected in the field.
- Pest outbreaks found in field studies were rarely linked to natural enemy reduction.
- Predictive value of laboratory bioassays was deemed low in this case study.

GRAPHICAL ABSTRACT



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ABSTRACT

The nontarget effects of insecticide programs used to control codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), were studied in large-plot field trials in apples, pears, and walnuts in the western United States. We assessed the health of the natural enemy community by sampling the abundance of natural enemies and by monitoring for outbreaks of secondary pests. The insecticides used in the field tests overlapped those tested in laboratory bioassays. Using these parallel lab and field studies, we examined two hypotheses: 1) pesticides found to have negative effects on natural enemy fitness in laboratory bioassays will predict reductions in natural enemy densities in the field, and 2) reductions in natural enemy densities in the field will result in outbreaks of secondary pests. We found only one clear instance, *Forficula auricularia* (L.) (Dermaptera: Forficulidae), where laboratory results documenting negative effects corresponded to a significant reduction in field studies (apple). This same instance was the only case where a reduction in a natural enemy population was associated with a significantly increased density of a secondary pest, *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae). There were several instances where secondary pest outbreaks were associated with unchanged or even increased natural enemy densities. The limited number of field trials, variability in field trial conditions among years and sites, duration of the negative effect relative to sampling interval, sampling efficiency, plot size/inter-plot movement, and compensation by other natural enemies attracted to a large host/prey

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resource may all have contributed to the poor predictive success. Overall, the laboratory bioassays predicted a far greater negative impact than was found in the field trials.

1. Introduction

Decades of progress in developing and implementing more selective, sometimes species-specific controls for key/direct pests has left researchers with a new challenge: biological control of secondary pests (Blommers, 1992). Many of these pests are classed as induced pests, or ones whose natural enemies typically suppress them to low levels in the absence of pesticides. Most of the indirect pests (those feeding on plant tissues other than the marketable commodity) fall into this class; because of their feeding habits, higher densities of these pests are tolerated before an economic injury level is reached (Stern et al., 1959). This allows the latitude necessary for biological control to operate, with a zero-tolerance quarantine pest at the opposite end of the spectrum. The challenge then, becomes finding a suite of control tactics for key pests that will not disrupt control of secondary pests (Hoyt, 1969).

Laboratory bioassays of insecticides are arguably the most popular method of judging the potential impact on natural enemies and the efficacy of biological control. The coordinated testing program of the International Organization for Biological Control (IOBC) (Hassan, 1987; Hassan et al., 1991, 1988; Sterk et al., 1999) represents the most comprehensive and sustained effort in this area. The IOBC tiered testing approach, where only those materials found harmful in laboratory studies are tested in semi-field and field tests, has provided a robust method for evaluating nontarget effects. Early screening efforts were relatively simple measurement of acute mortality, but over the years, laboratory methodology has grown increasingly sophisticated, including the use of multiple life stages, sublethal effects and population-level responses. The driving motivation behind these changes was to provide a more detailed and accurate picture of toxicological effects, which would in turn provide a better prediction of field effects (Bartlett, 1964; Croft, 1990; Desneux et al., 2007; Haynes, 1988; Stark and Banks, 2003; Stark et al., 2007; Wennergren and Stark, 2000).

Given the widespread use of laboratory bioassays for predicting field effects, relatively few studies have been devoted to assessing the accuracy of the predictions. Most of these studies refer to the IOBC rating system (Armenta et al., 2003; Raudonis et al., 2004; Rodrigues et al., 2002; Thomson and Hoffman, 2006; Tillman and Mulrooney, 2000). However, some authors promote a more experiential approach to understanding nontarget effects, using less detailed data taken directly from large-scale (spatial or temporal) field studies (Blommers, 1992; Pickett and McPhee, 1965). The latter approach is expensive, and thus difficult to sustain over long periods of time.

This paper is a case study comparing field studies (Beers et al., 2016 and Shearer et al., 2016) with lab studies (Mills et al., 2016a,b) that were designed in concert and conducted over a relatively short time period. Using these parallel lab and field studies, we examined two hypotheses: 1) pesticides found to have negative effects on natural enemy fitness in laboratory bioassays will predict reductions in natural enemy densities in the field, and 2) reductions in natural enemy densities in the field will result in outbreaks of secondary pests. We used a meta-analysis of the field results across multiple sites, years and crops to determine whether the population density of secondary pests or natural enemies increased, decreased, or were unchanged by pesticide applications, and the relative impact on vital rates from Mills et al. (2016) and published literature to assess the severity of pesticide effects in laboratory studies.

2. Materials and methods

2.1. Laboratory bioassays

A detailed description of the organisms tested, pesticides, and methodology for the laboratory studies are given in Mills et al. (2016), Amarasekare et al. (2016) and Amarasekare and Shearer (2013) and are briefly summarized here. Six arthropod species were tested using a life-table approach, with multiple bioassays testing different stages and responses in order to parameterize a stage-structured matrix model (PopTools, Hood (2010)). Two of the species tested (*Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) and *Trioxys pallidus* Haliday (Hymenoptera: Aphidiidae)) were sampled at the species level in the field trials; the other four species (*Chrysoperla carnea* (Neuroptera: Chrysopidae), *Deraeocoris brevis* (Uhler) (Heteroptera: Miridae), *Hippodamia convergens* Guérin-Méneville (Coleoptera: Coccinellidae), and *Galendromus occidentalis* (Nesbitt) (Acarina: Phytoseiidae)) were reported as part of a higher taxonomic group (predatory Neuroptera, predatory Heteroptera, Coccinellidae, and Phytoseiidae, respectively). Of the seven pesticides or pesticide mixtures tested in the laboratory, only five were used in one or more field trials, which varied among crops (Table 1).

2.2. Field studies

The field studies were conducted in three growing regions in the western U.S.: apples in central Washington, winter pears in the Hood River Valley of Oregon, and walnuts in the Sacramento Valley of California (see Shearer et al., 2016 and Beers et al., 2016a,b for a full description of methods). All study sites were in major production regions for their respective crops. The field studies were designed to test the potential disruptive effects of insecticides on secondary pests and their natural enemies, specifically those likely to be used against *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). The treatments were similar among the crops, but were tailored to probable commercial use patterns in the respective crops. While the key pest, *C. pomonella*, was the same, the secondary pests studied varied by crop. In apple, the secondary pests sampled included aphids (woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae); apple aphid, *Aphis pomi* De Geer (Hemiptera: Aphididae); and rosy apple aphid, *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae)) and tetranychid mites (European red mite, *Panonychus ulmi* (Koch) (Acari: Tetranychidae) and twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae)). In the pear studies the only secondary pest of importance was pear psylla (*Cacopsylla pyricola* Förster (Hemiptera: Psyllidae)); although spider mites are pests of pear, the levels in our experiments were too low to merit reporting. In walnut, aphids (walnut aphid, *Chromaphis juglandicola* (Kaltenbach) (Hemiptera: Aphididae)) and tetranychid mites (*P. ulmi* and *T. urticae*) were the most prevalent secondary pests.

Eleven field experiments were conducted from 2008 to 2011, using randomized complete block designs with 3–4 treatments. Each treatment was replicated 3–4 times in 0.27–0.61 ha plots. Depending on the year and the crop, the insecticide treatments