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Parasitoid wasp diversity in apple orchards along a pest-management gradient

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ABSTRACT

This study examined the impact of pest-management practices on Hymenopteran parasitoid diversity and assemblage composition in six apple orchards in southeastern Michigan, USA. The orchards comprised a gradient of pest-management intensity from organic to IPM to conventional practices. We used a pesticide toxicity index to quantify monthly and seasonal pest-management intensity in each orchard and conducted monthly vacuum-sampling of wasps during summer of 2009.

Monthly toxicity scores predicted wasp abundance, setting an upper bound on the number of wasps in the orchard, but did not predict species richness. Total species richness was significantly higher in the organic orchard than in all others, but in August a conventional orchard had the highest wasp abundance and species richness. These results suggest that a toxicity index could guide pesticide choices or application times so as to increase parasitoid wasp populations, which have untapped potential for pest management in apple orchards.

1. Introduction

Apple orchards provide a useful system for comparing the effects of different pest-management strategies on natural-enemy arthropod diversity. Due to intensive production methods and minimal market tolerance for damaged fruit, conventional apple growers have relied on frequent applications of broad-spectrum pesticides, especially organophosphates, to control arthropod pests (Jones et al., 2009; Lacey and Unruh, 2005; Perry et al., 1996). For example, in 1996, Michigan apple growers applied up to eight different fungicides and 10 different insecticides at weekly intervals, resulting in up to 15 pesticide applications during the growing season (Perry et al., 1996). Motivated by government regulations restricting organophosphate use, the development of pest resistance to common orchard pesticides, rising pesticide costs, and public concern over pesticide exposure, apple growers and agricultural agencies are increasingly turning to integrated pest management (IPM) practices to reduce pesticide use and increase biological control of major orchard pests (Agnello et al., 2003; Gut and Brunner, 1998; Jones et al., 2009; Prokopy et al., 1996; Suckling et al., 1999).

Parasitic Hymenoptera are common natural enemies that prey on key apple pests, including codling moth, *Cydia pomonella* (Lacey and Unruh, 2005), various species of leafroller and leafminer moths (Cross et al., 1999; Hull et al., 1997; Wilkinson et al., 2004), and woolly apple aphid, *Eriosoma lanigerum* (Cross et al., 1999; Shaw and Walker, 1996). Parasitoid wasps offer a potential means of biological control of these orchard pests (Hull et al., 1997; Jones et al., 2009; Van Driesche and Taub, 1983). Arthropod natural enemies such as parasitoid wasps appear to be more abundant and have higher species richness within organic agroecosystems than conventional ones (Bengtsson et al., 2005; Hole et al., 2005; Letourneau and Bothwell, 2008; Macfadyen et al., 2009). Parasitoid wasps are especially sensitive to pesticides, including fungicides and many insecticides that are less harmful to other beneficial arthropods (Hassan et al., 1987, 1988, 1994; Sarvary et al., 2007; Suckling et al., 1999; Thomson and Hoffman, 2006). Thus, parasitoid wasp diversity can serve as an indicator of both overall orchard toxicity and the potential for increased biological control after reducing pesticide use.

This study examined parasitoid wasp species richness, abundance, and assemblage composition from May through August 2009 in apple orchards under various pest-management strategies (organic, varying IPM, and conventional). A toxicity gradient for the orchards was determined using an index based on toxicity class and frequency of application (Thomson and Hoffman, 2006) and wasp diversity was compared along that gradient. We evaluated (1) how parasitoid wasp diversity (abundance and species richness) varied in relation to pesticide toxicity and (2) how monthly patterns

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of toxicity and parasitoid wasp diversity compared to an overall seasonal "snapshot".

2. Methods

Sampling took place at six apple orchards in southeastern Michigan, located between 43.02° and 41.77°N latitude and 83.62° and 84.60°W longitude. The orchards represented a range of sizes, tree ages and pest-management practices as summarized by the growers (Table 1). *Org* was a certified organic orchard. *ABO* used advanced IPM practices which the owner called "all but organic". *IPM-d* had diverse plantings of tree and soft fruits as well as vegetables. *IPM-i* was a large, intensively managed orchard. *Conv-d* was an older, conventional orchard with diverse plantings of tree and small fruits. *Conv* was a small conventional orchard. Groundcover in all orchards consisted mostly of grass mixed with small amounts of *Trifolium* spp., *Taraxacum officinale*, *Daucus carota*, *Plantago* spp. and other common weedy species.

Some orchards had multiple planting locations and interspersed blocks of apple trees with other crops; therefore, rather than record overall orchard size, we calculated orchard block size based on the area occupied continuously by apple trees and bordered by hedgerows, other crops, or significant roads. Orchard block size varied from 1.6 to 22.3 ha (Table 1). A study plot was established within each orchard at least 17.7 m from any block edge. Each plot consisted of 10 Red Delicious apple trees divided into two adjacent rows of five trees each, except at *Conv*, which had only one row of Red Delicious containing all 10 sample trees.

2.1. Orchard pesticide use and IOBC toxicity index

We collected 2009 pesticide application records from each orchard and conducted an 1 h interview with each grower to clarify spray records and assess cultural pest-control practices, pest-management philosophy, and attitudes toward orchard natural enemies. Growers reported major pests, which were also observed in the orchards during sampling: fruit pests such as *C. pomonella* and *Grapholita molesta*, and foliage pests including various leafrollers and leafminers, European red mites (*Panonychus ulmi*) and aphids. All pesticides were assumed to be applied at the industry-recommended spray rate and concentration unless noted otherwise by the grower.

To determine a toxicity class for each pesticide, we used the database of pesticide toxicity to beneficial arthropods maintained by the International Organization for Biological Control of Noxious Animals and Plants—Pesticides and Beneficial Organisms Working Group (IOBC) (http://www.iobc-wprs.org/ip_ipm/03022_IOBC_PesticideDatabase_2005.pdf). Following the method of Thomson and Hoffman (2006, 2007), a toxicity class was assigned to each pesticide on a scale of 0–2 from the lowest to highest mortality class. Assigning a zero value to pesticides causing <30% mortality effectively eliminated these pesticides from each orchard's toxicity calculation. For pesticides not included in the IOBC database, we found studies that evaluated toxicity to parasitoid wasps, giving preference to studies that followed IOBC testing procedures (see Table S1 and associated references). We calculated cumulative IOBC toxicity scores for each orchard by multiplying the toxicity class of each pesticide by the number of times that the pesticide was applied from the start of the season through the August sample date, and then summing toxicity scores for all pesticides used. Monthly IOBC toxicity scores were calculated using the time between sample dates to represent each month.

In addition to pesticides, the orchards utilized cultural or physical pest-management practices. *Org* used pheromone mating disruption to control *C. pomonella*, while *ABO* used mating disruption to control both *C. pomonella* and *G. molesta*. *IPM-i* delayed spring mowing of the orchard floor to allow predatory mites to migrate from overwintering sites into the apple trees, and *Org* limited mowing to preserve weeds that could serve as alternative pollen and nectar sources for predatory arthropods. All six orchards utilized some form of scouting and trapping in 2009 to monitor pest populations. *Org* and *ABO* routinely contracted a professional orchard scout who visited each orchard weekly, *IPM-i* employed a scout as part of regular orchard staff, and *IPM-d*, *Conv-d*, and *Conv* utilized a scout in 2009 provided gratis by a local pesticide company.

2.2. Parasitoid sampling and identification

Sampling occurred on May 14–21, June 17–26, July 21–30, and August 16–21, 2009, using a modified leaf blower/vacuum with fine ($\leq$30 μm) mesh bags fitted into the tube to vacuum-sample arthropods for one min from the middle and lower canopy of each of 10 apple trees. Arthropod samples from each of the 10 trees were sampled, stored, and analyzed separately. Mesh sampling bags were placed into sealable plastic bags with a cotton pad soaked in 99.5% ethyl acetate and stored in a chilled cooler in the field. In the laboratory, parasitic Hymenoptera were separated from other arthropods and debris, and then stored in the freezer. Identified wasps were stored in 95% ethyl alcohol.

Hymenoptera were identified to family (Borror and White, 1970; Borror et al., 1989; Grissell and Schauff, 1990) and morphospecies (http://hol.osu.edu/) and counted. Voucher specimens were stored at the University of Michigan Museum of Zoology, Insect Division. Wasps from May samples were difficult to identify to morphospecies due to immediate storage in alcohol and were therefore counted for abundance estimates only.

2.3. Data analysis

Effects of individual orchard practices on total parasitoid wasp abundance were evaluated via one-way analysis of variance (ANOVA), using Welch's *F* statistic and Games–Howell post hoc tests to account for unequal variances (Howell, 2010; Zar, 1999). We used repeated-measures ANOVA to evaluate the effect of orchard practices on monthly parasitoid wasp abundance, using orchard, month, and their interaction as fixed effects, with a compound-symmetric covariance structure to account for repeated measurements with non-independent residuals for the same tree over time. Bonferroni corrections were used for multiple comparisons. All abundance data were *ln*-transformed to improve normality.

The relationship between monthly IOBC toxicity scores and wasp abundance was analyzed using a linear mixed model (LMM) (Molenberghs and Verbeke, 2000). We allowed orchard to be a random effect to control for differences in initial wasp abundance within each orchard due to factors other than 2009 pest-control practices. Since the subject of analysis was the individual tree measured repeatedly over time, a compound-symmetric covariance structure was used to account for non-independent measurements within each tree and potential pseudoreplication (Fernando Chaves, 2010). The LMM model was also used to assess the influence of two potential confounding factors on wasp species richness: orchard block size, which could affect immigration and recolonization potential, and tree age, since older trees can support greater arthropod diversity (Brown and Schmitt, 2001). Finally, we used ordinary least-squares linear regression to determine whether IOBC toxicity scores predicted wasp abundance within individual orchards. Linear mixed models and regressions were calculated with SPSS Version 18.0 (IPM Software, Chicago, IL, USA).