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Connecting natural enemy metrics to biological control activity for aphids in California walnuts

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HIGHLIGHTS

- Conservation biological control needs natural enemy metrics that predict pest control.
- Natural enemy diversity metrics and predator-prey ratios were tested as possibly useful metrics.
- Predator-prey ratio and percent parasitism are correlated with current biological control.
- Natural enemy units showed promise, but density dependence confounds the results.
- No natural enemy metrics were found to suitably predict future biological control potential.

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ABSTRACT

To encourage adoption of conservation biological control, metrics need to be developed that can predict current activity and future potential of biological control. In this study, we evaluated natural enemy metrics to see how well they performed in predicting current and future biological control of *Chromaphis juglandicola* in California walnut orchards. Metrics based on more direct measures of natural enemy activity, such as percent parasitism and predator–prey ratio, were effective indicators of current biological control activity. Of the natural enemy metrics based on biodiversity, only evenness had a significant relationship with current aphid density, and only in organic orchards. There were two apparent negative relationships between the seasonal change in aphid density and natural enemy metrics, weighted natural enemy units and weighted predator units. June aphid density alone had the strongest influence on the seasonal change in aphid density, however, suggesting that even at low densities walnut aphids show within-year density dependence. Coupled with strong positive relationships between both natural enemy units and predator units and current aphid densities, most likely due to aggregation, this suggests that the apparent predictive power of these two metrics between seasons was an artifact of the density dependence. Overall, the results from this study suggest that for walnut aphid, predator–prey ratio, parasitism and natural enemy evenness (in organic orchards only) can be used to evaluate current biological control activity, but predicting future control potential through the season from natural enemy metrics can be misleading due to the confounding effect of within-year density dependence.

1. Introduction

Biological control is a vital ecosystem service, the economic value of which is often under-appreciated (Losey and Vaughan, 2006; Power, 2010; Naranjo et al., 2015). Conservation biological control, the enhancement of resident natural enemies for the suppression of pest abundance, is often underutilized in many agricultural crops and yet provides a way to substantially reduce pesticide use without sacrificing crop yield (Jonsson et al., 2008). While conservation biological control is supported by a growing body of literature (Ehler, 1998; Jonsson et al., 2008; Chaplin-Kramer and Kremen, 2012; Wyckhuys et al., 2013) its unpredictability often makes it problematic for farmers to rely on natural enemies alone or to effectively incorporate them into their decision making. Even with the promise of economic gains, farmers are unlikely to adopt conservation biological control if it is too difficult to understand or utilize (Cullen et al., 2008). Thus there is a growing need to provide farmers and pest control advisers with relevant, easy to use, and well tested metrics that they can use to

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measure the extent of the biological control services present in their fields, as a means to lower the barriers to adoption.

A more standardized and reliable way to (1) determine if biological control has contributed effectively to pest suppression in a crop at the current time, and (2) predict whether it will continue to be effective through the rest of the season, would greatly improve the adoption of conservation biological control as a management practice. In particular, what is needed are metrics that can easily be measured in a crop and that would allow decision makers to know when biological control by resident natural enemies is, or is not, sufficient to prevent crop damage. Decision makers need to know what measure of local natural enemy activity best describes the extent of biological control present in a crop, and what response in local pest activity best shows that the desired level of pest suppression has been achieved. A wide variety of metrics for natural enemy abundance and diversity and pest responses have been used in the literature in the context of measuring biological control, including a biocontrol services index (Gardiner et al., 2009) and a natural pest suppression index (Bennett and Gratton, 2012), but there remains no consensus regarding the most effective measures to use. Nonetheless, connecting predictive metrics to appropriate response variables is essential for integrating conservation biological control into farmer decision making (Macfadyen et al., 2015).

The relationship between natural enemy diversity and biological control services is part of the larger debate about the relationship between biodiversity and ecosystem function. Understanding the effect of biodiversity on ecosystem function, however, is an important step for effective management of important ecosystem services (Kremen, 2005; Balvanera et al., 2014). While a general positive relationship between biodiversity and ecosystem function has been found across a range of ecosystem services, there has also been substantial variation in the direction and magnitude of such effects (Balvanera et al., 2006; Letourneau et al., 2009; Balvanera et al., 2014). Much variation has even been observed within specific ecosystem services, particularly in the relationship between natural enemy diversity and biological control (Gurr et al., 2012; Crowder and Jabbour, 2014). Studies have shown positive (Snyder et al., 2006), neutral (Macfadyen et al., 2009; Crowder et al., 2010) and even negative (Finke and Denno, 2004; Vance-Chalcraft et al., 2007) effects of increasing natural enemy richness on the effectiveness of biological control (Letourneau et al., 2009). Some of this variation could stem from the use of differing metrics. The meta-analysis of Balvanera et al. (2006) showed that the principle measure of biodiversity has been species richness, accounting for 393 out of the 446 studies analyzed. Interestingly, the meta-analysis also showed a significant effect of the type of biodiversity measure used – richness, functional richness, diversity or evenness – suggesting that differing metrics could contribute to the variation in observed effects. Use of species or taxon richness as the only measure of diversity may neglect the ecological importance of evenness and of other aspects of diversity, such as functional diversity (Cadotte et al., 2011; Crowder and Jabbour, 2014). Clarifying which components of biodiversity and what mechanisms drive relationships with particular ecosystem services continues to be an important challenge (Balvanera et al., 2006).

Aphids, as pests of many crops (Van Emden and Harrington, 2007; Dedryver et al., 2010), support diverse natural enemy communities that include parasitoids, fungal pathogens, and a wide range of predators (Volkl et al., 2007). Nonetheless, as aphids can cause notable economic damage by reducing yield, they are often suppressed through application of insecticides (Dedryver et al., 2010). Exploiting the latent ecosystem service of conservation biological control in many aphid systems could reduce insecticide use and support sustainable crop management practices. In California, walnut is an important tree crop that has historically sustained damage from the aphid *Chromaphis juglandicola* (Kaltenbach) (Hemiptera: Aphididae). This aphid was successfully controlled through the intentional introduction of the Iranian strain of the parasitoid *Trioxys pallidus* (Hymenoptera: Braconidae) in 1969 (Van den Bosch et al., 1979), however, renewed outbreaks have recently been reported (Hougardy and Mills, 2009). Currently, in-season insecticide treatments are sporadically used for the management of walnut aphid. In California, walnut aphid has no known fungal pathogens, but is attacked by a limited number of predator species in addition to *T. pallidus*. The renewal of insecticide use in walnuts could be reduced if we had the necessary tools to be able to predict the contribution of natural enemies to the suppression of aphid populations in both the short term and over longer periods during the growing season.

Although complex models have been developed to help identify the factors most likely to cause change in aphid population densities within and between seasons (Morgan, 2000; Gosselke et al., 2001; Mashanova et al., 2008; Valpine and Rosenheim, 2008; Day et al., 2010), they have not been put to practical use by farmers or pest managers (Kindlmann and Dixon, 2010). However, Hallett et al. (2014) received a positive response from the farmers who tested a much simpler model that was developed to incorporate the contribution of biological control services into the decision making process for management of aphids in soybeans. More research is needed to develop and test similar practical tools for decision making in pest management and to ensure that they incorporate the most useful metrics for measuring biological control services in a variety of cropping environments.

In this study, we used the walnut aphid system to investigate the utility of a set of natural enemy metrics for predicting the contribution of biological control to walnut aphid management. Our objectives were (1) to evaluate how selected natural enemy metrics of abundance and diversity relate to current and seasonal changes in aphid densities using field observations, and (2) to determine which predator metrics predict current predation pressure using field experimentation. As aphid suppression in walnuts in California is thought to be driven primarily by the introduced parasitoid *T. pallidus* (Frazer and Van den Bosch, 1973; Van den Bosch et al., 1979), our hypothesis was that both current and seasonal change in aphid densities would be negatively correlated with current parasitism, and that neither would be influenced by metrics of natural enemy biodiversity. In other words, orchards with higher parasitism rates would have fewer aphids and would show a decrease in aphid abundance over the season, but that there would be no influence of natural enemy biodiversity. A second hypothesis was that ratio metrics (such as predator–prey ratio) would predict current predation pressure on walnut aphids, but would not predict change in aphid density through the growing season as predators are not thought to control aphids in this system (Sluss, 1967). To be able to predict the current status and future potential of biological control of aphids in a walnut orchard from easily applied monitoring protocols would aid farmer decision making and encourage the adoption of conservation biological control (Kremen, 2005; Tscharntke et al., 2012).

2. Methods

2.1. Observational field sampling

In 2012, six pairs of organic and conventional orchards were sampled. Each pair was of similar age and located with 2 km of each other. The same 12 orchards were re-sampled and an additional four pairs of organic and four conventional orchards were added in 2013 in order to increase the geographic range covered. All of the orchards were in the Central Valley of California, between