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Research Paper

Comparison of invertebrate biodiversity in New Zealand apple orchards using integrated pest management, with or without codling moth mating disruption, or organic pest management

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ABSTRACT

On-farm biodiversity is increasingly perceived as an indicator of sustainable practices. However, in-depth examinations of the influence of management on the components of this diversity (specific taxa, feeding guilds, pests, ecosystem service providers, native taxa, and so on) are still lacking for many crops and growing regions. To compare the diversity of invertebrates in commercial apple orchards using three different pest management systems (Integrated Fruit Production with or without codling moth mating disruption and certified organic), we collected taxa from five of each type of orchard in Hawke's Bay, New Zealand. We used pitfall traps, branch tapping and sticky traps to collect 210,829 specimens, representing 764 taxa, during two sampling sessions: December 2011 and February/March 2012. Groundcover plant communities in the alleys between tree rows were not detectably different among the three orchard types. Multivariate analysis showed that the composition of invertebrate communities sampled from organic orchards differed significantly from those in orchards using the two different integrated pest management systems and that the use of codling moth disruption in the integrated systems had no discernible impact on invertebrate biodiversity in those orchards. Sub-group analysis revealed some differences between integrated and organic orchards for herbivores, predators and parasitoids, but not omnivores, detritivores and fungivores. Native or endemic species comprised 40% of taxa in all three orchard types, and there were no detectable differences in the composition of these assemblages among orchards. Assemblages of apple pests in organic orchards differed significantly from those in the other orchard types, but this effect was lost if *Edwardsiana froggatti*, which was abundant in organic orchards, was omitted from the analysis. All orchard types had similar assemblages of key natural enemies, suggesting that current integrated pest management systems employed on apple orchards in New Zealand have similar impacts to organic systems in this respect.

1. Introduction

Biodiversity, and the ecosystem services it can provide, are increasingly recognised as an important part of sustainable food production (e.g., Anon, 2015b). Audit schemes run by retailers of horticultural produce include on-farm biodiversity conservation requirements (e.g., Anon, 2016) and the concept that consumers are willing to pay more for products which support biodiversity is being researched (Bantle and Hamm, 2014; Saunders et al., 2010).

In orchards, invertebrates contribute to fruit production via biological control of pests, decomposition and pollination (Cross et al., 2015). Links between the diversity of invertebrates and the provision of pollination and biological control services have been demonstrated in other systems (e.g., Rader et al., 2012; Tylianakis and Romo, 2010). As relatively stable and architecturally complex agro-ecosystems, orchards may also provide habitats for a variety of invertebrate species and thereby contribute a 'cultural service' to broader biodiversity conservation goals (e.g., preservation of native species) (Horak et al., 2013). The value of collecting and analysing region-specific data on invertebrate biodiversity and ecosystem service providers was highlighted in a recent global study that showed different impacts of land-use change on pollinators in different regions (De Palma et al., 2016).

Any efforts to increase invertebrate biodiversity on orchards must be compatible with pest control and biosecurity requirements, which are often country-specific. Meeting the dual goals of suppressing insect pests and maintaining invertebrate biodiversity-provided ecosystem

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services is particularly challenging when the fruit are destined for markets with high phytosanitary requirements. Even natural enemy and native species that are considered beneficial where the fruit are grown may be classed as 'passenger pests' in other countries. For example, *Lasioglossum sordidum* is a New Zealand native bee which is classified as an actionable pest on apples exported to the USA (Anon, 2013).

In recent decades, there has been a significant trend in horticulture towards adopting integrated pest management systems and using lower volumes of more selective, less toxic pesticides. This trend has been driven primarily by concerns about human and environmental health, including a need to reduce the effects of pesticides on non-target invertebrates, particularly those involved in pollination or pest and disease suppression (Brittain et al., 2010; Geiger et al., 2010).

Pesticide use on apple orchards in New Zealand (8566 ha planted in 2015 (Anon, 2015a)), has decreased markedly over the last 20 years with the adoption of an Integrated Fruit Production (IFP) programme (Walker et al., 2017), and, more recently, growers of apples for export to Europe have adopted 'Apple Futures', a new ultra-low pesticide residue programme (Walker et al., 2015). Residue-free pest control options such as pheromone-based mating disruption (Walker et al., 2013) and biopesticides have also been adopted by some growers, and others use certified organic growing systems (about 6% of New Zealand's current apple production is certified as organic (Anon, 2015a)). The importance of natural enemy species in suppressing pest populations is widely understood among commercial apple growers in New Zealand (Walker et al., 2017), but the last surveys to examine the impacts of pest management programmes on the diversity of natural enemy species, or on total invertebrate biodiversity, in New Zealand apple orchards were carried out in the late 1990s (Suckling et al., 1999; Wearing, 1997; Wearing et al., 2011b). Exporters of New Zealand apples to Europe comply with GLOBALG.A.P (Good Agricultural Practice) certification schemes, which include a 'minor must' requirement to 'maintain biodiversity on the farm' (Anon, 2016; Walker et al., 2017). A better understanding of the current status of on-orchard biodiversity in New Zealand apple orchards, and the impacts of pest management on it, would help growers to formulate more effective action plans to meet this requirement, without compromising pest control or production goals.

Here we compare invertebrate fauna in commercial apple orchards using three different pest management systems: IFP, IFP with codling moth mating disruption (IFPMD) and organic. Our goal was to examine the structure of invertebrate communities in the different orchards, including an analysis of sub-groups of taxa that could provide insight into the provision of biodiversity-based ecosystem services in the orchards. In addition to total invertebrate biodiversity, functional groups were examined to discern any potential differences in trophic structures and the provision of decomposition, herbivory and predation services, native species were examined to determine if orchard management could influence the potential for orchards to play a role in the conservation of native taxa in managed landscapes, and pests and their natural enemies were examined to gain insight into the influence of orchard management on the provision of pest biocontrol services in New Zealand orchards producing apples for export.

2. Methods

2.1. Orchards and pest management practices

Fifteen commercial apple orchards in Hawke's Bay, New Zealand (0–10 m above sea level, 39°32′ – 39°40′ S, 176°50′ – 176°54′ E) were studied, with five representing each of three different pest management systems: IFP, IFPMD and organic. All orchards were commercially viable and had blocks producing 'Braeburn' fruit that met export standards for quality and yield. One of these blocks (0.27-2.91 ha in size) in each orchard was used in this study. A map indicating distances between blocks is provided in the Appendix, Fig. A1 . Rootstocks were unknown for ten of the orchards, 'M106′ for two and 'M793′ for three, and planting dates were 1984 for one orchard, 1990 for two, and unknown for the rest (although tree size indicated that they were of similar ages). Trees were planted 2–3.5 m apart in rows that were 4.2-5.9 m apart; tree densities were similar among blocks within and between each group of five blocks. Blocks were chosen to minimise any differences (e.g., cultivar, tree age, growing system, irrigation, planting density, pruning system, prevailing wind, aspect, soil type) other than the pest management system used. Predominant land uses in this region were apple or stonefruit orchards, vegetable crops, vineyards and pastures. Some orchards were also near low-density residential housing, public parks, roadways, rivers or streams. Two of the IFP orchards, three of the IFPMD orchards, and two of the organic orchards were protected from the wind (SW prevailing in winter, ENE in summer) by shelterbelts comprising various tree species trimmed to a height of 6–10 m.

IFP and IFPMD orchards were managed according to the requirements of Pipfruit New Zealand's IFP programme (Lo et al., 2015; Walker et al., 2001). This programme had been subject to minor, ongoing modifications since its inception, but at the time of this study, each orchard had been using essentially the same pest management system since 2009. Codling moth mating disruption (Nomate® CM, Scentry Biologicals, USA) was used in each of the IFPMD orchards and had been since 2009; two of the IFPMD orchards had also used Isomate® C Plus (Shin-Etsu Fine Chemicals Ltd, Japan) dispensers for two seasons before that (Walker et al., 2013). Organic orchards had been managed to meet International Federation of Organic Agriculture Movement accreditation standards for at least six years (in addition to a three-year conversion period before that). In brief, the IFP programmes promoted the minimal targeted use of selective insecticides, timed according to pest monitoring protocols, and organic production forbade the use of synthetic chemical pesticides and fertilisers (Appendix, Table A1).

2.2. Invertebrates and groundcover plants

Invertebrates were sampled from each orchard on two occasions: 14–21 December 2011 (developing fruitlets on the trees) and 27 February-6 March 2012 (ripe fruit, expected to be ready for harvest in late-March or early April).

In each study area, ten trees at random locations were selected and tagged to act as sampling loci. Trees in rows next to the edges of an orchard block, and those at the ends of rows, were excluded. A pitfall trap and a yellow sticky trap (hung on a branch about 1.3 m above the ground) were placed at each locus, and collected after seven days. Pitfall samples were stored at 4 °C and sticky traps at −20 °C. Branch-tapping samples were also taken from each locus using a padded stick to tap 20 branches, at a height of about 1.1 m, on separate trees along the row from each locus for about 10 s each, and stored at −20 °C. Any live lepidopteran larvae were placed individually in plastic containers on general purpose artificial diet (Singh and Moore, 1985) and kept at 20 °C so that emerging adults or parasitoids could be identified.

Groundcover plant species were identified (Roy et al., 2004) and their percentage cover estimated from 0.5 m^2 quadrats placed in the middle of the alley between the rows of trees at each locus (12–14 December 2011). 'Grasses' were not identified to species, except for paspalum (*Paspalum dilatatum*), Yorkshire fog (*Holcus lanatus*) and cocksfoot (*Dactylis glomerata*), and 'bare ground' was included as a category. Notes were also taken on the treatment of the under-tree strip (herbicide or not), and the identity of any plant species growing within a 0.3 m radius of the trunk of each tagged tree recorded. Mowing frequency data were not available, but a qualitative two-point assessment (frequent or infrequent mowing) based on the height of vegetation and the presence of dead clippings in the alleys was made at the time of groundcover assessment.

For identification, cool-stored invertebrates were transferred directly to 95% v:v ethanol in glass vials. Invertebrates on sticky traps

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