Population dynamics of bronze beetle, *Eucolaspis* spp. (Coleoptera: Chrysomelidae) in relation to other soil macro-invertebrates in organic apple orchards in Hawke's Bay

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Abstract The population structure and dynamics of bronze beetle, *Eucolaspis* spp., and other soil macro-invertebrates were studied in eight organic apple orchards in Hawke's Bay during spring/summer 2007-08. Orchards with high bronze beetle population densities also had higher abundance of all types of soil macro-invertebrates than orchards with low bronze beetle populations. Surface-dwelling generalist predators were more numerous (on average 53.6 versus 40.5 predators per trap) in orchards with low bronze beetle density than in orchards with high beetle density. This result was mainly due to spider numbers in pit-fall traps, which were highest during January. It may be that within orchards where surface-dwelling spiders are most abundant, these spiders may be predating upon newly emergent adult bronze beetles as they move from the soil to the apple foliage.

Keywords bronze beetle, *Eucolaspis,* Chrysomelidae, Coleoptera, organic apple, soil macro-invertebrates, generalist predators.

INTRODUCTION

Organic apple (*Malus domestica* Borkh.) production in New Zealand has increased since the first exports began in 1998, largely attributed to increased public awareness of pesticides and global demand for organic produce. Currently New Zealand has slightly under 800 ha of organic apple orchards, exporting ~$NZ28 million worth of produce (The Horticulture and Food Research Institute of New Zealand Limited 2006; Plant & Food Research Institute of New Zealand Limited 2008). A tiny native chrysomelid beetle, commonly called bronze beetle, is posing a significant threat to this organic apple industry, especially in the Hawke's Bay region. Bronze beetle (*Eucolaspis* spp.) is complex containing several species, but the taxonomy is relatively unresolved (Kay 1980; Dugdale & Hutcheson 1997). Adult beetles damage developing fruitlets during spring and early summer resulting in a raised scab on the mature fruit skin, rendering the fruit below export standard. Yield losses due to bronze beetle damage have been estimated to reach 43% (Rogers et al. 2006).

The *Eucolaspis* spp. larvae live in the soil, feeding on grass roots and hibernating during winter. The fully-grown larvae move towards the top soil layers during early spring and pupate in small earthen cells. The adults emerge during spring and live for up to a month, feeding on a wide range of host plant leaves and fruits, including those of apple trees (Lysaght 1930; Miller 1971; Rogers et al. 2006). Bronze beetle was a major orchard pest during the early 20th century (Miller 1926), but became rare after the introduction of organo-chlorine and other broad spectrum insecticides in fruit production (Clearwater & Richards 1984).

Bronze beetle damage has been shown to vary greatly between and within organic apple orchards in Hawke's Bay. This variation was not attributable to orchard management practices or site physical characteristics, and the population variations remained fairly consistent over 2 years of observation (Rogers et al. 2006, 2007). This suggests some other ecological factor may be influencing bronze beetle populations in different orchards. The aim of this research was to investigate whether soil invertebrate community structure in organic apple orchards correlated to different bronze beetle population densities.

MATERIALS AND METHODS

Study sites

Eight certified organic orchards containing blocks of 'Royal Gala' apples in Hawke's Bay were selected. Among these, four orchards had a history of high bronze beetle damage (will be referred to as "High bronze beetle orchards" from hereon) and the other four orchards had a history of low damage (will be referred to as "Low bronze beetle orchards"). The beetle damage histories were established through previous studies by Rogers et al. (2006, 2007) and by talking to orchard owners.

Soil sampling

Five soil samples per orchard were collected once a month for 4 months, starting from October 2007 to January 2008. Soil samples (18 × 18 cm, 14 cm deep) were obtained by digging with a spade beneath a branch within a 1 m radius from the five randomly selected apple tree trunks (Rogers et al. 2007). The samples were transferred to the lab in clear plastic bags and stored at 4°C until processed for macro-invertebrates.

All soil samples were hand-sorted and macro-invertebrates found were counted, identified to species/genus/family level and stored in 70% ethanol.

Pitfall trap sampling

Pitfall traps were set up beneath the tree line within a 1 m radius from the trunk of five randomly selected trees during October 2007. The pitfall traps comprised a small plastic cup (250 ml capacity) inserted into a PVC pipe (8.0 cm diameter) sunken into the soil and flush with the soil surface level. A corrugated iron lid was placed on top to protect the trap from rainwater flooding, allowing a gap for crawling invertebrates. The trap was half-filled with Polyethylene Glycol (PGPLUS Concentrate – Fleetguard, Australia) to preserve invertebrates (Minor & Robertson 2006). The traps were permanently positioned for the entire sampling period.

Captured invertebrates were retrieved from all traps once a month for 4 months from November 2007 to February 2008. A small quantity of 70% ethanol was added to each sample once brought to the lab. The samples were then stored at room temperature until processed. All macro-invertebrates collected were counted and identified to species/genus/ family level.

Statistical analysis

All macro-invertebrates were grouped into three main trophic groups based on their feeding habits (herbivores, detritivores and predators) for data analysis according to the following references (Petersen & Luxton 1982; Dindal 1990; Bejakovich et al. 1998; Minor & Robertson 2006). Herbivores data were further divided into bronze beetles and other herbivores. The predators data from pit-fall traps were further split into spiders, predatory beetles (Carabidae and Staphylinidae), centipedes and other predators (ants, flatworms and earwigs) for additional analysis. The data set was merged by orchards within the high previous bronze beetle versus low previous bronze beetle history in order to test for differences between the two orchard history types. Poisson regression (Proc Genmod, SAS 9.2) was used to analyse the datasets; χ^2 and P-values from type3 likelihood ratio analysis were used to compare the effects.

RESULTS

Both the sub-soil and surface-dwelling macro-invertebrate samples obtained by soil sampling and pitfall trapping, respectively, were numerically dominated by detritivores. Herbivores were the second largest group found in the sub-soil, whereas predators were second largest group in the surface-dwelling macro-invertebrate community.

Bronze beetles

The density of bronze beetles (cumulative total of larvae, pupae and adults) in soil samples varied between different orchards ($P<0.0001$ – Poisson regression type3 analysis of likelihood ratio). As expected, significantly higher numbers of beetles were found in High bronze beetle orchards than in Low bronze beetle orchards (Table 1). Among all the orchards, during October, H3 orchard had the highest bronze beetle density whereas L4 orchard had zero bronze beetles (Figure 1). Larvae were the most abundant life stages of bronze beetle during October and in all orchards the beetle density in soil samples decreased over the sampling period as the adults emerged and left the soil (Figure 2).

Very few bronze beetle adults were collected in pitfall traps, with none in the November and February samples.

Other herbivores

Herbivores (other than bronze beetles) found in soil samples were mainly immature stages of Coleoptera and Diptera. These declined in abundance over the sampling period. High bronze beetle orchards had significantly more other herbivores than Low bronze beetle orchards in all sampling months (Table 1).

Adult Coleoptera (Scarabeidae and Elateridae) comprised the majority of the very few surface-dwelling herbivores found in pitfall traps. High bronze beetle orchards had slightly fewer other herbivores than Low bronze beetle orchards, although the differences were not significant during the sampling period (Table 2).

Detritivores

Earthworms were the most abundant detritivores found in the soil samples followed by Isopoda. The differences in abundance of detritivores between High bronze beetle orchards and Low bronze beetle orchards were only significant during the January and February sampling periods (Table 1).

Surface-dwelling detritivores caught in pitfall traps were mostly Isopoda and Amphipoda; their abundance varied greatly over time. January samples had the highest density of detritivores between the four sampling periods. The differences in abundance of detritivores between High bronze beetle orchards and Low bronze beetle orchards were significant throughout the sampling period (Table 2).

Predators

Generalist sub-soil predators were mostly Chilopoda (centipedes) along with a few insecta (Carabidae – ground beetles, Formicidae) and Turbelleria (terrestrial flatworms). The density of soil predators was higher in High bronze beetle orchards than in Low bronze beetle orchards. Although, this difference was significant during all the sampling periods, it became more obvious during January and February (Table 1).

The surface-dwelling predator community structure was relatively similar across all the orchards. Spiders (Araneae) outnumbered all others, representing about 80% of the predators caught in all pitfall traps. The surface predators were significantly more abundant in Low bronze beetle orchards than in High bronze beetle orchards throughout the sampling period (Table 2). Spiders were more abundant in Low bronze beetle orchards than in High bronze beetle orchards on all sampling dates. Although predatory beetles (December, January and February samples) and other predators such as ants (January and February samples) were significantly more abundant in Low bronze beetle orchards, the numerical difference was small. Centipedes were more abundant in High bronze beetle orchards than in Low bronze beetle orchards in January and February (Table 3).

DISCUSSION

The variation in bronze beetle populations found between the two selected groups of orchards corroborates with previous history (Rogers et al. 2006; Rogers et al. 2007) and growers' observations. Although High BB orchards had more sub-soil generalist predators (mostly centipedes), their soil also supported higher bronze beetle population densities, and much higher other herbivores living within the soil (Table 1) than Low BB orchards. It is possible that the centipede populations benefited from high seasonal bronze beetle populations but did not contain them. The reason for this is not known. There may be some other as yet unidentified factor responsible for the consistent differences in bronze beetle population densities between orchards. For instance that all soil dwelling macroinvertebrate groups were at higher densities in those high bronze beetle orchards suggests that differences in soil productivity or health may somehow be related to bronze beetle attack history.

Historically low bronze beetle orchards had significantly more surface-dwelling predators than historically high bronze beetle orchards. Further analysis showed this was purely due to spider numbers. Many researchers have previously reported reductions in pest populations due to successful predation pressure by surface-dwelling generalist predators. For instance, the surface-dwelling generalist predator population was enhanced by habitat manipulation, resulting in successful control of *Cydia pomonella* (Lepidoptera) in apple orchards (Mathews et al. 2004). Spiders have been reported to limit pest populations in apple orchards (Marc & Canard 1997), in citrus groves (Mansour & Whitecomb 1986) and have been shown to feed on many pest taxa including Coleoptera, Lepidoptera, Hemiptera and Diptera (Symondson et al. 2002; Maloney et al. 2003).

Large populations of generalist predators supported by a range of prey species are capable of providing efficient biocontrol for a pest species, switching to the pest prey during its availability (e.g. a pest outbreak), and returning to alternative prey species when the pest population declines (Symondson et al. 2002). It therefore may be possible that the generalist surface dwelling spiders, which must feed on other prey throughout the year, may be able to utilize the soft and vulnerable emerging adult bronze beetle as a facultative prey as they emerge from the soil during early summer. After this time bronze beetles tend to feed, mate and live within the foliage, and would be more vulnerable to aboreal predators than ground dwelling predators. So whether ground dwelling spiders whose population was highest during the

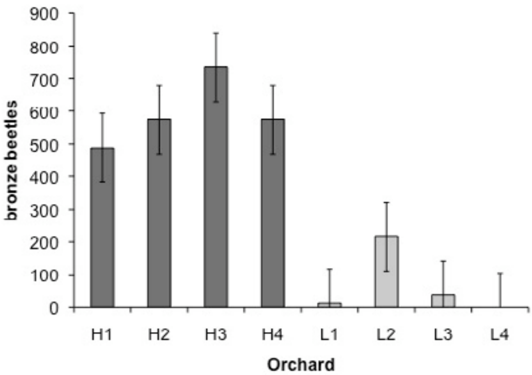

Figure 1 Total number of bronze beetles (larvae + pupae + adults)/m^2 (mean ± SEM) found in the soil. Data are for October 2007 when beetle density in the soil was at its highest. H1-H4: orchards with high bronze beetle damage; L1-L4: orchards with low bronze beetle damage.

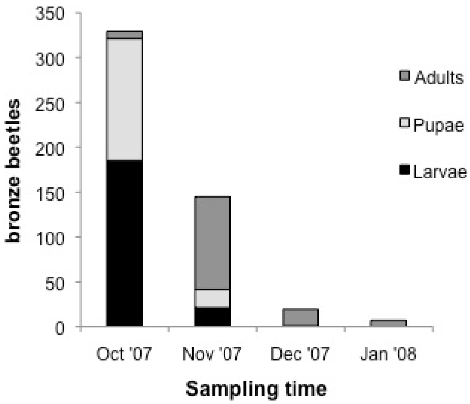

Figure 2 Relative abundance (mean number of individuals/m^2 across all the orchards) of different life stages (larvae, pupae and adults) of bronze beetle in soil over the sampling period.

Table 1 Sub-soil macro-invertebrates (mean number/m^2) in orchards with a history of high and low bronze beetle damage.

Previous	Predators				Bronze beetle				Other herbivores				Detritivores			
history	Oct	Nov	Dec	Jan	Oct	Nov	Dec	Jan	Oct	Nov	Dec	Jan	Oct	Nov	Dec	Jan
High bronze beetle	274.7	106.5	185.2	120.4	592.6	265.4	34.0	12.3	561.7	402.8	188.3	216.0	899.7	409.0	696.0	478.4
Low bronze beetle	142.0	66.4	29.3	37.0	66.4	24.7	4.6	1.5	242.3	189.8	104.9	57.1	935.2	429.0	521.6	273.1
χ^2 value	27.88	6.09	81.8	30.1	313.0	151.18	16.31	6.2	84.56	50.72	15.56	63.88	0.44	0.31	16.24	36.79
P-value	<.0001	.014	<.0001	<.0001	<.0001	<.0001	<.0001	.013	<.0001	<.0001	<.0001	<.0001	.505	.577	<.0001	<.0001

Table 2 Surface-dwelling macro-invertebrates (mean number/trap) caught over the preceding month in pitfall traps in orchards with a history of high and low bronze beetle damage.

Previous	Predators				Bronze beetle				Other herbivores				Detritivores			
history	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb
High bronze beetle	23.79	35.35	66.60	35.45	0	0.95	0.1	0	4.1	3.15	2.55	1.85	83.79	56.6	137.35	71.15
Low bronze beetle	40.75	44.85	84.68	45.55	0	0.15	0	0	4.6	3.25	2.84	1.80	114.75	97.85	221.37	125.4
χ^2 value	87.69	22.56	42.27	25.25		12.97			0.51	0.03	0.31	0.01	94.34	223.04	387.85	303.4
P-value	<.0001	<.0001	<.0001	<.0001		.0003			.46	.86	.58	.91	<.0001	<.0001	<.0001	<.0001

Table 3 Abundance of different surface-dwelling generalist predator taxa (mean total number/trap) in orchards with a history of high and low bronze beetle damage.

Previous	Spiders				Predatory beetles[1]				Centipedes				Other predators[2]			
history	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb
High bronze beetle	19.05	30.30	55.15	29.75	1.42	1.60	3.10	1.35	0.26	0.40	2.70	1.20	3.05	3.05	5.65	3.15
Low bronze beetle	31.80	35.45	71.58	38.25	2.00	2.95	5.53	3.65	0.50	0.25	1.26	0.40	6.45	6.20	6.31	3.25
χ^2 value	62.8	8.08	41.67	21.31	1.92	8.13	13.51	21.98	1.45	0.7	10.35	8.37	24.13	21.89	0.72	0.03
P-value	<.0001	.005	<.0001	<.0001	0.166	.004	.0002	<.0001	.228	.403	.0013	.004	<.0001	<.0001	.395	.86

[1]Predatory beetles = Carabidae and Staphylinidae. [2]Other predators = ants+flatworms+earwigs.

month of January are responsible for containing the population growth of bronze beetle populations in Low BB orchards needs more research. Observation of specific predation by spiders on bronze beetles emerging from the ground is needed to add support this hypothesis. The current findings could not explain conclusively why some orchards have more spiders than others.

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