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Short and long-term impacts of ultra-low-volume pesticide and biopesticide applications for locust control on non-target arid zone arthropods

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ABSTRACT

While locust control is necessary to avoid the high cost of locust damage to agriculture, land managers are increasingly seeking to minimize the environmental impact of pesticide spray treatments used. The comparative impacts of different locust control treatments on non-target arid zone fauna are rarely studied in the field, leading to uncertainty as to which treatments represent the lowest hazard to the sprayed ecosystems.

A phenyl pyrazole pesticide, fipronil, and a fungal biopesticide, *Metarhizium acridum* (Green Guard®) were applied aerially in either a barrier or blanket ULV treatment at replicated sites which mimicked the techniques employed for locust control operations in Australia. Effects of the two pesticide treatments were compared in the absence of dense locust populations. We measured the abundance and community composition of non-target arid-zone arthropods at control and treatment sites before and after pesticide applications using a large field-based pitfall trapping experiment.

Arthropod community composition was not significantly affected over time by either locust control treatment. However, significant short-term times × treatment interactions were found for 6 of 11 most common taxa at family or higher taxonomic level (collembolans, acarians, coleopterans, psocopterans, gryllids, and dipterans).

We also compared unsprayed and sprayed areas within fipronil and *Metarhizium* treatment sites, and found 2 of the 10 most common ant species (Formicidae: *Rhytidoponera mayri* and *Iridomyrmex purpureus*) showed significant time × treatment interactions for fipronil but none for *Metarhizium*, indicating that ants were more severely affected by fipronil within sites than between the three treatments.

One year post-treatment, significant time × treatment interactions persisted for only two taxa (dipterans and blattodeans) at *Metarhizium* treatments, indicating full recovery of most taxa. The suppression of the ant *R. mayri* in fipronil sprayed areas within treatment sites persisted after one year, while *I. purpureus* had fully recovered. Relative arthropod abundance and community assemblage changed over time in control and treatment sites, probably reflecting changes in patterns of local rainfall over the study period.

Most of the statistically significant treatment effects recorded for different taxa in our study were not long lasting, suggesting that the two locust control methods studied represent a relatively low and transient hazard to most arthropod taxa. The pronounced temporal variation in arthropod abundance across all sites indicated that climate and environmental factors are likely to be stronger drivers of arid zone arthropod abundance and community structure than single aerial applications of low-dose aerial pesticide treatments used to control locusts in arid and semi-arid regions of Australia.

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1. Introduction

Interest in minimizing the environmental impact of pesticide spray treatments has grown since the mid-twentieth century when chemical pesticides were first used in large-scale locust control operations (Krall et al., 2012). Worldwide, locust control operations employ preventative treatments of both chemical and biological insecticides to reduce the migratory capacity of locust populations outside of agricultural areas (Story et al., 2005; Krall et al., 2012) and preventing movement into productive agricultural systems. In Australia, arid and semi-arid rangelands are infrequently subjected to pesticide treatments for locust control and individual sites rarely receive repeated treatments (Story et al., 2005). Although locust control in Australia has typically employed fast acting organophosphorus pesticides such as fenitrothion, which are cost-effective and have a relatively short half-life (Story and Cox, 2001), the more persistent phenyl pyrazole pesticide, fipronil, is also used for aerial applications (Story et al., 2005). Research in Madagascar and Australia has shown that single high dose applications of fipronil (3.2–7.5 g active ingredient a.i. ha^{-1}) as a blanket treatment can cause significant reductions in the abundance of key terrestrial arthropods and their vertebrate predators (Peveling et al., 2003). However, in Australia fipronil is now applied at much lower doses (0.25–1.25 g a.i. ha^{-1}) and in spatially-separated narrow strips across a target area, with the effectiveness of this 'barrier' treatment relying on bands of locusts contacting the pesticide strips as they move across the landscape. Fipronil barrier treatments are potentially less hazardous to non-target fauna due both to the low dose used and the smaller area receiving direct pesticide application (Peveling, 2001; Story and Cox, 2001; Story et al., 2005). However, there is little information on the relative ecological benefits of applying the more persistent pesticide fipronil as a lower-dose barrier treatment, despite the assumption that the implementation of methods treating smaller areas represents lower risk.

In addition, several effective biological pesticides have been developed in response to the increased importance of environmentally friendly pest control options (Butt et al., 2001). These include a specific strain of the entomopathogenic fungus *Metarhizium acridum* (marketed as Green Guard®, MycoBank MB512407), which is used in Australia and thought to be largely specific to locusts (Bischoff et al., 2009). Australian endemic, taxon-specific *Metarhizium* spp. strains have been used effectively in the control of coleopteran and hemipteran pests, such as the rice weevil *Sitophilus oryzae* and pod bug *Clavigralla tomentosicollis* (Zimmermann, 2007). Different *Metarhizium* strains have been found to infect over 14 orders of arthropods (Butt et al., 2001). While strains isolated from soil are highly virulent, they are less host specific than strains which were isolated from insect cadavers (Zimmermann, 2007). However, without laboratory or field-testing, the possibility that each *Metarhizium* spp. strain will have unexpected impacts on a range of non-target arthropods needs to be considered when evaluating the environmental risks associated with locust control. A small number of studies have documented increased mortality of beneficial coleopterans, dipterans, neuropterans, cladocerans and hemipterans following field or lab applications of *Metarhizium* spp. strains (James and Lighthart, 1994; Milner et al., 2002; Thungrabeab and Tongma, 2007).

This study tested the comparative effects on non-target arthropods of two relatively unstudied forms of locust control treatment used in Australia, using a large-scale replicated field experiment. We assessed the impact of pesticide applications used in the field by applying fipronil barrier treatments and *M. acridum* (hereafter referred to as *Metarhizium*) blanket treatments. Although large numbers of locust pests were not present during the study, we applied standard single application treatments on an operational scale and monitored their relative impacts on non-target terrestrial arthropods using pitfall trap captures. If locust control treatments affected other arthropods, we predicted that there would be less arthropod activity within sprayed than unsprayed areas in the short-term. Over longer periods, we predicted that non-target invertebrates would recover fully when the pesticide treatment followed single application ultra-low-volume locust control practices.

2. Methods

2.1. Site

The study was conducted at Fowlers Gap Arid Zone Research Station (31.087034°S, 141.792201°E) near Broken Hill, NSW, Australia. The property is a working sheep station also managed for biodiversity conservation. It is within the geographical region of western New South Wales where high density locust populations are periodically recorded, although no previous locust control treatments have been recorded on the property. The site has cool winters and hot summers (average maximum temperature for Jan: 36 °C; Australian Bureau of Meteorology), with annual rainfall during the study of 526 mm in 2011, 321 mm in 2012, 98 mm in 2013 and 194 mm in 2014. All sites selected within the research station property were located in treeless arid grassland habitat dominated by perennial grasses (*Astrebla, Dichanthium, Panicum* and *Eragrostis*) and low shrubs (Chenopodiaceae species).

2.2. Design

To test the effects of each of the two pesticide treatments on arthropods, we used a BACI (before, after, control, impact) experimental design (Green, 1979). Arthropod captures in pitfall traps were recorded before and after treatments in sprayed and unsprayed plots. We considered that any changes in either the arthropod assemblage composition, or in the relative abundance of individual taxonomic groups, should provide evidence of the magnitude of any impact on terrestrial arthropods and allow insight into the relative hazards presented by these two locust control methods. Impacts of treatments on arthropods were determined for two temporal scales; short-term (20 days before and after treatments), and longer-term (one year before and after treatments). Medium term impacts were not accessed, due to the likely confounding factor of season. Cold winter conditions occur within two months of typical locust control operations and arthropod activity and survival is naturally depressed during winter (Briese and Macauley, 1980; Hunter et al., 2001). Short-term impacts would then represent any immediate effects of treatments and form a 'worst case' comparison to longer-term impacts. Any impacts detected after a year would suggest if the treatments also resulted in arthropod population declines severe enough to interrupt longer-term reproduction and recruitment within populations, which determine species persistence in an environment (Stark and Banks, 2003).

Nine 1-km diameter circular sites (79 ha) were spaced at least 2 km apart to avoid potential spray drift reaching non-treatment sites (Hooper, 1998). Three sites were randomly allocated to each of three treatments; control, fipronil treatment and *Metarhizium* (Supplementary material, Fig A.1). Within each site we established six monitoring arrays in a pattern including a centre array and five perimeter arrays, all 200 m apart or greater. To determine perimeter array directions and distances from the centre, we used random number generation to define the angle within each of five sections of a circle and a location between 200 and 500 m from the centre array. This resulted in n = 18 replicate arrays per treatment. Each array consisted of twelve traps (67 mm diameter