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Comparative effects of pesticides, fenitrothion and fipronil, applied as ultra-low volume formulations for locust control, on non-target invertebrate assemblages in Mitchell grass plains of south-west Queensland, Australia

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ABSTRACT

The effect of an aerial application of two broad-spectrum insecticides, the organophosphorus compound, fenitrothion, and the phenyl pyrazole pesticide, fipronil, on non-target invertebrates was investigated during Australian plague locust (*Chortoicetes terminifera*, (Walker, 1870)) control operations on a Mitchell grass (*Astrebla* spp.) plain in south-western Queensland, Australia, between 2002 and 2004. The invertebrate assemblages were monitored using yellow pan and Malaise traps to target flying invertebrates and pitfall traps to target ground-dwelling invertebrates, sampled immediately before spraying and then at 3, 7, 39, 79, 189 and 414 days after spraying. Both pesticides caused significant changes to invertebrate community composition immediately after spraying, largely due to changes in the abundance of Orthoptera, Collembola and Formicidae. The richness and abundance of invertebrates in Malaise and yellow pan traps did not differ significantly with pesticide application although significant changes in assemblage composition persisted for up to 79 days. Although not statistically significant, the richness and abundance of invertebrates in pitfall traps declined at sprayed sites after treatment, relative to controls. Assemblage composition in pitfall traps at sprayed sites was significantly different from that in the control sites and these differences persisted for up to 189 days post-spray. Prolonged drought across the study site is likely to have affected the recovery of invertebrate populations and a return to pre-spray abundances did not occur until after heavy rain fell approximately one year after the commencement of the study. The controlling influence of climatic conditions on recovery of non-target arthropod populations after exposure to pesticides therefore has implications for risk assessments for the use of pesticides in arid environments.

1. Introduction

Periodic outbreaks of locusts are a threat to agricultural production in several countries. In Australia, locusts were first reported harming crops near Adelaide in 1844 (Szabo et al., 2003) and the aerial application of chemical pesticides for the management of populations of the Australian plague locust, *Chortoicetes terminifera* (Walker, 1870) has been a fixture in arid and semi-arid agro-ecosystems since the inception of the Australian Plague Locust Commission (APLC) in 1976 (Hunter, 2010; Story and Cox, 2001).

Locust control in Australia is undertaken using ultra-low volume aerial applications of insecticides that follow standard operating procedures allowing spray parameters to be varied depending on locust life stage, weather, and vegetation type. Historically, the APLC has relied on the organophosphorus pesticide, fenitrothion (O,O-dimethyl O-(3-methyl-4-nitrophenol) phosphorothioate - Sumitomo Chemical, Osaka, Japan) as the most cost-effective control agent to suppress locust populations but concerns about its environmental impact in other countries have led to its registration being reviewed and the increased use of the phenyl pyrazole pesticide fipronil (5-Amino-1-[2,6-dichloro-4-(trifluoromethyl)

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phenyl]-4-[(trifluoromethyl)sulfinyl]-1H-pyrazole-3-carbonitrile) for locust control in Australia (Story et al., 2005).

Fenitrothion is a broad spectrum insecticide used throughout the world for the control of agricultural and forest pest and disease vectors affecting humans and animals (Story and Cox, 2001) and has been shown to adversely affect non-target arthropod populations in both aquatic (Lahr et al., 2000a, 2000b) and terrestrial ecosystems in studies spanning several decades (Alford, 1991; Carter and Brown, 1973; Chiverton, 1984; Freitag et al., 1969; Freitag and Poulter, 1970; Peveling et al., 1999, 2003; van der Valk, 1988). Early research into the effects of the organophosphates, Sumithion (fenitrothion) and phosphamidon ((*E*/*Z*)-[3-Chloro-4-(diethylamino)-4-oxobut-2-en-2-yl] dimethyl phosphate) used for spruce budworm (*Choristoneura fumiferana* (Clemens, 1865)) control in Canadian forest ecosystems demonstrated suppressions in abundances of five carabid beetles (*Agonum retractum* (LeConte, 1846), *Calathus ingratus* Dejean 1828, *Pterostichus pensylvanicus* LeConte, 1873, *Scaphinotus bilobus* (Say, 1823) and *Sphaeroderus nitidicollis* Guérin-Méneville, 1829) and one species of spider (*Trochosa terricola* Thorell, 1856) for up to 15 weeks after the initial pesticide application (Freitag et al., 1969). Further research showed that populations remained suppressed in sprayed areas for up to 12 months when compared to control plots (Freitag and Poulter, 1970).

Like most organophosphorus insecticides, fenitrothion has a relatively short half-life in full ultra-violet light (approximately 18–23 h (Greenhalgh et al., 1975)) and so suppressions in non-target arthropod populations for up to 12 months after pesticide application does not imply a residual effect of the chemical, but rather longer term disruption to the ecosystem being studied (Freitag and Poulter, 1970). Fenitrothion also causes temporary effects on some predacious arthropod components of epigeal fauna. Populations of *Escaryus* spp. (centipede), *Microbisium* sp. (pseudo scorpion), and two species of harvestmen, *Leiobunum calcar* Wood, 1868 and *L. bicolor* (Wood, 1870) were suppressed after fenitrothion applications in stands of red spruce (*Picea rubens* Sargent, 1898), while a third harvestman species, *Odiellus pictus* (Wood, 1879), was unaffected (Carter and Brown, 1973). Spiders of the family Erigonidae were also unaffected by the fenitrothion application. A high degree of variation in pre-treatment captures during the study prevented proper calibration of the dataset prior to treatment and therefore it was not clear whether population reductions were due to direct toxicity of the pesticide or a reduction in available prey items (Carter and Brown, 1973). Similar increases in activity and capture success of the beneficial Coleopteran, *Pterostichus melanarius* (Illiger, 1798) along with a concomitant decrease in prey populations were observed during large scale field trails to assess the effects of fenitrothion and Sumicidon (fenvalerate, (RS)-*alpha*-Cyano-3-phenoxybenzyl (RS)-2-(4-chlorophenyl)-3-methylbutyrate) on beneficial arthropods in barley crops (Chiverton, 1984).

In Australia, the impact of aerially applied fenitrothion on non-target invertebrate populations has been evaluated previously (Carruthers et al., 1993, 2000; Hooper et al., 2000; Walker et al., 2000). This research quantified the effects of fenitrothion application at 381 g of active ingredient (ai) per hectare as an ultra-low volume (ULV) treatment for locust control on the epigeal invertebrate fauna of arid grasslands at five locations throughout eastern Australia. More than 331,000 arthropods were caught in pitfall traps with the Collembola, which constituted the majority of captures, being the most sensitive invertebrate group to the pesticide application. A significant reduction in the total number of arthropods caught was detected at most sites immediately after spraying, but most of the fauna had fully recovered by 28 days post-treatment (Carruthers et al., 1993). Longer-term effects on the abundance of Collembola were seen throughout the 5 trial sites, but no differences in species diversity or community structure were detected at the two sites studied in detail. It was concluded (Hooper et al., 2000), that the application of fenitrothion at 381 g ai ha^{-1} would only have short-term effects on the epigeal invertebrate fauna of arid grasslands of eastern Australia. Despite the efficacy of fenitrothion for locust control, concerns about its environmental impact in other countries led to its registration being reviewed in Australia and the APLC investigating alternative control agents and application methodologies for use against locusts (Story et al., 2005).

Fipronil is a broad-spectrum, low-dose insecticide that works via direct contact and stomach action (Story et al., 2005) and is highly effective against both the nymph and adult stages of locusts and grasshoppers. Although not as fast acting as some other insecticides currently used for locust control (e.g. fenitrothion), it does work at very low doses and has a longer residual activity (Tingle et al., 2000; van der Valk, 2006). Fipronil is an extremely active molecule and is a potent disrupter of the insect central nervous system via interference with the passage of chlorine ions through the chlorine channel regulated by gamma-aminobutyric acid (Hainzl et al., 1998). The efficacy of fipronil against various locust species has been demonstrated in Africa in both laboratory and field assessments at application rates ranging between 4 and 20 g ai ha^{-1} (see (Balanca and de Visscher, 1997a, b) for a detailed review of trials and their locations). However, application rates of 4 and 13.2 g ai ha^{-1} reduced the abundance of non-target invertebrates (Carabidae, Hymenoptera and Tenebrionidae) by between 70% and 90% of pre-spray abundances respectively, with recolonisation taking approximately 2 weeks for the lower dose and up to 4 weeks for the higher dose (Balanca and de Visscher, 1997a). In Queensland, Australia, mound-building and subterranean termites (Isoptera) have been shown to be very sensitive to fipronil (Steinbauer and Peveling, 2011) applied as a blanket pesticide application at a rate of approximately 1.25 g ai ha^{-1}. However, no significant impact of fipronil on wood-eating termites in arid western New South Wales, Australia was detected when fipronil was applied as a barrier treatment, significantly reducing the amount of pesticide applied (approximately 0.75–1 g ai ha^{-1}) and increasing areas of untreated habitat by spraying the pesticide in strips (Maute et al., 2016). Elsewhere, Peveling et al. (2003) showed that fipronil application for locust control caused up to 90% mortality in termite colonies, as well as declines in the abundance of key termite predators, the lesser hedgehog tenrec, *Echinops telfairi* Martin 1838 and the lizards *Trachylepis elegans* (Peters, 1854) and *Chalarodon madagascariensis* Peters, 1854.

Many non-target arthropods affected by non-specific, broad spectrum insecticides are key elements of food webs in (agro-) ecosystems and have important functions such as pollination, nutrient cycling, and predation and parasitism of crop pests (including locusts). It is critical therefore, that the environmental consequences of this pest management strategy are quantified fully. The aim of this study was to assess the effects of fenitrothion and fipronil on non-target invertebrates within a Mitchell grass (*Astrebla* spp.) plain agro-ecosystem in south-west Queensland, Australia.

2. Materials and methods

2.1. Location and spray application

In February 2002, an infestation of Australian plague locust nymphs (*C. terminifera*) occurred on two adjacent properties, 'Ray' (26′ 05″, 143′ 43″) and 'Thylungra' (26′ 05″, 143′ 27″) stations, situated between the townships of Quilpie and Windorah