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Mosquito control insecticides: A probabilistic ecological risk assessment on drift exposures of naled, dichlorvos (naled metabolite) and permethrin to adult butterflies

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HIGHLIGHTS

- Application of mosquito insecticides posed risk to Florida native butterflies.
- Naled and permethrin posed higher risk than did dichlorvos.
- Risk changed with time and location.
- Risk due to naled application in the field increased over time.
- Risk due to permethrin application in the field decreased over time.

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ABSTRACT

A comprehensive probabilistic terrestrial ecological risk assessment (ERA) was conducted to characterize the potential risk of mosquito control insecticide (i.e., naled, it's metabolite dichlorvos, and permethrin) usage to adult butterflies in south Florida by comparing the probability distributions of environmental exposure concentrations following actual mosquito control applications at labeled rates from ten field monitoring studies with the probability distributions of butterfly species response (effects) data from our laboratory acute toxicity studies. The overlap of these distributions was used as a measure of risk to butterflies. The long-term viability (survival) of adult butterflies, following topical (thorax/wings) exposures was the environmental value we wanted to protect. Laboratory acute toxicity studies (24-h LD50) included topical exposures (thorax and wings) to five adult butterfly species and preparation of species sensitivity distributions (SSDs). The ERA indicated that the assessment endpoint of protection, of at least 90% of the species, 90% of the time (or the 10th percentile from the acute SSDs) from acute naled and permethrin exposures, is most likely not occurring when considering topical exposures to adults. Although the surface areas for adulticide exposures are greater for the wings, exposures to the thorax provide the highest potential for risk (i.e., SSD 10th percentile is lowest) for adult butterflies. Dichlorvos appeared to present no risk. The results of this ERA can be applied to other areas of the world, where these insecticides are used and where butterflies may be exposed. Since there are other sources (e.g., agriculture) of pesticides in the environment, where butterfly exposures will occur, the ERA may underestimate the potential risks under real-world conditions.

1. Introduction

There is growing global interest and concern about the extinction and co-extinction (i.e., the loss of a species upon the loss of another species) of species, including butterflies (Thomas et al., 2004; Koh et al., 2007). Butterfly populations may be affected by natural (e.g., temperature and climate changes, precipitation, fire, competition, predators, parasites, and disease) as well as human (e.g., use of insecticides and herbicides, grazing, introduction of exotic species of plants and animals, habitat damage and habitat loss) factors (Asher et al., 2001). Understanding the causes for population declines and extinction is important in determining losses in biodiversity (Kotiaho et al., 2005).

Few investigations have studied the impacts and risks of pesticides on the abundance and diversity of butterfly populations. Early studies indicate that species number and abundance of butterflies within arable farmland were higher in unsprayed plots compared with areas treated with pesticides in accordance with typical farming practice (Rands

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and Sotherton, 1986). Feber et al. (1996) showed that butterfly populations were most closely associated with abundance of flowers of key nectar source species and herbicides that affected flower abundance reduced their populations. Feber et al. (2007) and Rundlof et al. (2008) demonstrated that organic farms attract more butterflies with greater diversity than conventionally managed farms. Longley and Sotherton (1997) identified a variety of factors that contribute to butterfly population size which include not only susceptibility to insecticides but also removal of nectar sources and larval host plants and species-dependent ecological factors while de Snoo et al. (1998), Redderson (1994), and Russell and Schultz (2010) noted that differences in species diversity and abundance of butterflies were affected by pesticides and other factors, like crop type and adjacent habitat.

The Department of the Interior-managed National Key Deer Refuge (NKDR) was established in 1957 on Big Pine Key, FL approximately 30-miles northeast of Key West (Monroe County) and consists of approximately 8500 acres owned and 2200 acres designated wilderness. The refuge is home to approximately 22 federally listed endangered and threatened species of plants and animals and is managed by the Department of the Interior. Furthermore, 68 out of the 106 butterfly species found in the Florida Keys have been reported in Big Pine Key (Minno and Emmel, 1993) which represents 41% of the total number of species of butterflies observed for the entire state (i.e., 164 species; Deyrup and Franz, 1994).

The NKDR on Big Pine Key is within the area treated with the mosquito adulticides, naled and permethrin by the Florida Keys Mosquito Control District (FKMCD) (FDACS, 2003). Naled and permethrin are each applied as an ULV (ultra-low volume) spray either aerially (naled) or by ground equipment (permethrin). Under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA), the U.S. EPA classifies both naled and permethrin, as highly toxic to aquatic organisms (fish, non-mollusk invertebrates) and honey bees, based on acute toxicity data. The honey bee (*Apis mellifera*) is the main beneficial, non-target insect species required for testing by chemical manufacturers of pesticides under FIFRA.

Baggett (1982) suggests that declines in the Florida leafwing (*Anaea troglodyta floridalis*) and Bartram's hairstreak (*Strymon acis bartrami*) butterfly populations in the Florida Keys were attributed to the application of adult mosquito control insecticides. Furthermore, the decline in the population of the federally endangered Schaus' Swallowtail was noted with the increased use of insecticides (naled, fenthion) (Emmel and Tucker, 1991). However, it was not until the late 1980s that insecticide exposures of naled were documented in butterfly habitats in the lower Keys. Drift residues of naled were sampled in pineland/hammock ecosystems following application in 1989, especially in Watson's and Cactus Hammock's of the NKDR (Hennessey and Habek, 1991). Naled residues were present in target and non-target areas (e.g., Watson's Hammock; no spray zone). Naled spray drift was recorded as far as 30 m into a no-spray zone which was habitat for populations of Schaus' Swallowtail.

In 1997–1998, a survey in the Keys also showed higher abundance of adult butterfly densities of one species where mosquito control applications were restricted (Salvato, 2001). In 1999, a study was also conducted in Florida to evaluate the impact of naled on honey bees as a result of exposure to aerial ULV applications during mosquito spraying by Manatee County MCD in Florida (Zhong et al., 2003). The range of dead honey bees per hive after spraying was 9–200 within 24 h after application and the average yield of honey bee per hive was significantly lower for naled-exposed hives. More recently, Zhong et al. (2010) demonstrated that, after applications, naled does drift into environmentally sensitive areas, producing exposures to non-target taxa, such as Lepidoptera.

Adult Lepidoptera are significant ecological resources in the pollination of flowers but their main ecological importance is their role as larvae and to some extent the adults in breaking down plant tissue (i.e., role in nutrient cycling) and that all stages of this insect order are prey for insectivorous predators (e.g., birds, bats, small mammals, and parasitoids) (Scoble, 1992). Butterflies may also be used as biological indicators of environmental quality (e.g., level of habitat degradation).

Thus far, our laboratory has demonstrated that naled and permethrin are more acutely toxic to larvae and adult butterflies than to honeybees (Hoang et al., 2011). However, although there is field exposure data for naled, dichlorvos (metabolite of naled) and permethrin following mosquito control operations, there is no comprehensive probabilistic ecological risk assessment (ERA) for butterflies exposed to naled (or dichlorvos) and permethrin using field data, based on use of U.S. EPA ERA methodology (U.S. EPA, 1998). In general, there are a limited number of ERAs for chemical stressors and butterflies (Barger, 2012; Sears et al., 2001; Wolt et al., 2003, 2005) in terrestrial ecosystems. A recent deterministic ERA approach, using risk quotients, was also conducted with six adult mosquito control insecticides and non-target organisms (except insects), and showed minimal risks (Davis et al., 2007). Therefore, the objective of this study was to conduct a comprehensive probabilistic ERA to quantify the probability (likelihood) and magnitude (extent) that adverse effects are occurring or will occur to adult butterflies as a result of thorax and wing exposures using actual environmental exposure concentrations following field applications of the adulticides (i.e., naled, permethrin) and dichlorvos in south Florida terrestrial ecosystems, like the National Key Deer Refuge, Big Pine Key, FL. Adulticide exposure to the thorax of caterpillars was not considered since an ecological risk assessment demonstrated that for native Florida butterfly caterpillars this route is not as significant as the dietary route of ingesting host plant leaves contaminated with adult mosquito control agents (Hoang and Rand, submitted for publication). Adult butterfly consumption of contaminated nectar was also not considered.

The importance of examining the ecological risk of the mosquito control insecticides lies in the frequency and extensive widespread use of mosquito adulticides in Florida and throughout the U.S., to control and eradicate vectors of human disease (i.e., Chikungunya virus or CHIKV; west Nile virus or WNV; dengue virus), adjacent to and within butterfly habitats and the potential atmospheric drift of these exposures to areas distant from their immediate application.

2. Methods

In our previous study (Hoang et al., 2011), actual exposure concentrations (AECs) of the adulticides from post-field applications of naled (and subsequent concentrations of the metabolite; dichlorvos) and permethrin from drift (on filter pads) in south Florida were compared to point estimates from acute toxicity effects data (i.e., 10th percentile of the species sensitivity distributions (SSDs)) for each insecticide to obtain a hazard quotient (HQ) (Suter, 2007). The hazard quotients (>1) for both permethrin and naled indicate that AECs of these insecticides, in the field, following mosquito control applications exceed 24 h LD50s and therefore present potential hazards to butterflies.

In this study, a probabilistic approach was used with the U.S. EPA ERA framework (U.S. EPA, 1998), which compares probability distributions of measured exposure concentrations of the mosquito adulticides after application in the field from approximately ten different exposure monitoring programs at sites in or near the NKDR in South Florida, with all species toxicity response (effect) data (SSDs) from our laboratory acute toxicity studies with adult butterflies (Hoang et al., 2011) to determine the degree of overlap, which is a measure of potential risk or the probability that a certain percentage of species may be adversely affected by exposures. Species acute toxicity studies consisted of tests conducted to determine LD50s of adult butterflies as a result of exposures of naled, dichlorvos or permethrin to the thorax and wings (Hoang et al., 2011). By using the range of environmental field