A framework for incorporating the toxicity of pesticide mixtures into ecological risk assessments

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Incorporating the Toxicity of Pesticide Mixtures into Ecological Risk Assessments

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Pesticides are widely used throughout the United States and are frequently detected as complex mixtures in aquatic habitats. Therefore, pesticide toxicity is an important component of risk assessments performed within different regulatory and policy contexts. Here we describe a process for assessing toxicity of three categories of pesticide mixtures; formulated products (one product containing multiple active ingredients), tank mixes (multiple pesticides applied simultaneously), and environmental mixtures (resulting from unrelated pesticide use over the landscape). Mixtures were assumed to be either dose-additive or response-additive, depending on the modes of action of the individual pesticide components. Toxicity estimates utilized two main pieces of information - exposure concentrations and toxicity-specific mode of action data. Exposure concentrations were generated using either EPA’s Pesticide Water Calculator (PWC), which incorporates chemical and application-specific parameters to calculate anticipated water concentrations over different durations, or utilizing directly from routine monitoring studies. Standard measures of toxicity (typically the LC\textsubscript{50} or the concentration that is lethal to 50% of the test organisms) were used to represent a given pesticide. Reflecting the three mixture categories, we predicted toxicity for formulated products containing organophosphates, co-applications reported in California’s Pesticide Use Reporting System, and ambient water quality monitoring data from Washington. Results show that predicting mixture toxicity is possible with currently available information, and these predictions can be used in regulatory situations and ecological risk assessments. Importantly, failing to consider mixture toxicity may underestimate pesticide risk, leading to erroneous risk conclusions and ineffective protections for aquatic species and habitats.

Formulated Products

Formulated products are produced and sold as one product containing multiple active ingredients, with the exact types and amounts of active ingredients shown on product labels. Here, additive toxicity (assuming response-additive) was enhanced in freshwater fish exposed to a mixture of cyhalothrin and chlorpyrifos as compared to either chemical singly.

Process:
- Active ingredients identified on registered product labels
- Toxicity-specific LC\textsubscript{50} values obtained from print and online sources (e.g., EPA reports)
- Pesticide water calculator (PWC) predicted exposure concentrations in generic aquatic habitats
- Dose-addition models (concentration-addition or response-addition) used to predict cumulative toxicity

Tank Mixes

Tank mixes occur when pesticide users apply multiple pesticides simultaneously at the use site. Many tank mixes are explicitly allowed on product labels, and their use is encouraged to increase pesticide efficacy. California Department of Pesticide Regulation (CDPR) maintains the largest publicly-available database of pesticide applications from which tank mixture application can be obtained.

Process:
- Active ingredients identified on registered product labels or from usage data (e.g., CDPR database)
- Toxicity-specific LC\textsubscript{50} values obtained from print and online sources (e.g., EPA reports)
- PWC (pesticide water calculator) predicted exposure concentrations in generic aquatic habitats
- Dose-addition models (concentration-addition or response-addition) used to predict cumulative toxicity

Environmental Mixtures

Environmental mixtures result from the unrelated use of multiple pesticides across the landscape, and are typically detected in ambient water quality monitoring. Pesticides that enter aquatic habitats following direct application, spray drift, and surface runoff from use sites can contaminate aquatic habitats, thereby posing a threat to the species occupying those habitats. In a typical year in the U.S., pesticides are applied at a rate of approximately five billion pounds of active ingredient per year. Ambient monitoring data shows that pesticide contamination in the nation’s freshwater habitats is ubiquitous, and that pesticides usually occur in the environment as mixtures. For example, USGS NAWQA monitoring detected two or more pesticides in more than 90% of samples from urban, agricultural, and mixed-use streams nationwide.

Analysis of CDPR data shows that naled was co-applied with malathion more than 1500 times in CA strawberries from 2008-2012. The majority of these co-occurrences occurred at the maximum labeled application rates (1 lb/acre and 2 lb/acre, respectively). No difference in application rate was observed for naled when applied singly or with another pesticide.

Example 1: Malathion and Naled applied to Strawberries

<table>
<thead>
<tr>
<th>Generic Aquatic Habitat</th>
<th>Malathion EEC (ppb)</th>
<th>Naled EEC (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal soil, 1x1x0.5m</td>
<td>76</td>
<td>-</td>
</tr>
<tr>
<td>small pond, 1x1x0.5m</td>
<td>50</td>
<td>2.5</td>
</tr>
<tr>
<td>small lake, 10x10x0.2m</td>
<td>0.9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Analysis of CDPR data shows that naled was co-applied with malathion more than 1200 times in CA alfalfa crops from 2008-2012. The majority of these co-occurrences occurred at the maximum labeled application rates (0.1 lb/acre and 1.25 lb/acre, respectively). No difference in application rate was observed for naled when applied singly or with another pesticide.

Example 2: Malathion and Permethrin applied to Alfalfa

<table>
<thead>
<tr>
<th>Generic Aquatic Habitat</th>
<th>Malathion EEC (ppb)</th>
<th>Permethrin EEC (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal soil, 1x1x0.5m</td>
<td>76</td>
<td>-</td>
</tr>
<tr>
<td>small pond, 1x1x0.5m</td>
<td>50</td>
<td>2.5</td>
</tr>
<tr>
<td>small lake, 10x10x0.2m</td>
<td>0.9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

CDPR data also shows that permethrin was co-applied with malathion more than 1200 times in CA alfalfa crops from 2008-2012. The majority of these co-occurrences occurred at the maximum labeled application rates (0.1 lb/acre and 1.25 lb/acre, respectively). No difference in application rate was observed for these two chemicals when applied singly or together.