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A Qualitative Meta-analysis Reveals Consistent Effects of Atrazine on Freshwater Fish and Amphibians

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The authors declare they have no competing financial interests.

Abbreviations:

EEC	expected environmental concentration
LOEC	lowest observable effect concentrations
TOF	testicular ovarian follicle
USDA	United States Department of Agriculture

Outline of Section Headers

OBJECTIVE: The biological effects of the herbicide atrazine on freshwater vertebrates are highly controversial. In an effort to resolve the controversy, we conducted a qualitative meta-analysis on the effects of ecologically relevant atrazine concentrations on amphibian and fish survival, behavior, metamorphic traits, infections, and immune, endocrine, and reproductive systems.

DATA SOURCES: We used published, peer-reviewed research and applied strict quality criteria for inclusion of studies in the meta-analysis.

DATA SYNTHESIS: We found little evidence that atrazine consistently caused direct mortality of fish or amphibians, but found evidence that it can have indirect and sub-lethal effects. The relationship between atrazine concentration and timing of amphibian metamorphosis was regularly non-monotonic, indicating that atrazine can both accelerate and delay metamorphosis. Atrazine reduced size at or near metamorphosis in 19 of 19 studies. Atrazine elevated amphibian and fish activity in 12 of 14 studies, reduced anti-predator behaviors in six of seven studies, and reduced olfactory abilities for fish but not for amphibians. Atrazine was associated with a reduction in 35 of 43 immune function endpoints and with an increase in 13 of 16 infection endpoints. Atrazine altered at least one aspect of gonadal morphology in eight of 10 studies, and consistently affected gonadal function, altering spermatogenesis in two of two studies and sex hormone concentrations in six of seven studies. Atrazine did not affect vitellogenin in five studies and only increased aromatase in one of six studies. Effects of atrazine on fish and amphibian reproductive success, sex ratios, gene frequencies, populations, and communities remain uncertain.

CONCLUSIONS: Although there is much left to learn about the effects of atrazine, we identified several consistent effects of atrazine that must be weighed against any of its benefits and the costs and benefits of alternatives to atrazine use.

INTRODUCTION

The herbicide atrazine (2-chloro-4-ethylamino-6-isopropyl-amino-s-triazine) is the second most commonly used pesticide in the United States (Kiely et al. 2004), and perhaps the world (Solomon et al. 1996; van Dijk and Guicherit 1999). It is a photosynthesis inhibitor used to control certain annual broadleaf weeds, predominantly in corn but also in sorghum, sugarcane, and other crops and landscaping. The environmental risk posed by atrazine to aquatic systems is presently being re-evaluated by the US Environmental Protection Agency (USEPA: USEPA 2003, 2007). One of the challenges in evaluating the safety of atrazine has been that its biological effects are highly controversial, and much of the debate in the literature has been targeted at its effects on freshwater vertebrates (Hayes 2004; Renner 2004).

There have been four reviews on the biological effects of atrazine, all of which were funded by the corporation that produced or produces this chemical (Giddings et al. 2005; Huber 1993; Solomon et al. 1996; Solomon et al. 2008). However, none of the past reviews used a meta-analytical approach to identify generalities in responses to atrazine exposure. Meta-analysis, as paraphrased from the USEPA, is the systematic analysis of studies examining similar endpoints to draw general conclusions, develop support for hypotheses, and/or produce an estimate of overall effects. This sort of weight-of-evidence approach would provide directional hypotheses for future work on atrazine. Furthermore, it would offer invaluable information to regulatory agencies on general and expected impacts of atrazine on freshwater vertebrates that