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Of Frogs & Rhetoric: The Atrazine Wars

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Abstract

In a scientific dispute over the effects of atrazine on amphibians, chemical industry–funded and publically funded scientists present stunningly contrasting constructions of atrazine's environmental concentrations, persistence, and potential to harm. Considerable scientific uncertainties and variable ranges allow authors to construct preferred versions of the story of atrazine. These incommensurate rhetorical constructions, more the result of competing economic and environmental interests than of any paradigmatic misalignments, have prolonged the dispute not only over atrazine's effects but also over whether its sales should be banned.

Keywords: atrazine, incommensurate communication, rhetoric of science, scientific controversy

Scientists have disagreed for over a decade about whether a popular agricultural herbicide, atrazine, is an endocrine disruptor (EDC) in amphibians exposed to concentrations previously considered safe. Although the European Union banned the sale of atrazine in 2003, a similar ban in the United States has not been enacted and is unlikely due, in part, to the ongoing scientific debate. On one side are scientists, all funded by the Syngenta Corporation, the principal producer of the world's supply of atrazine, who insist that atrazine is not an EDC disruptor in frogs exposed to the concentrations typically found in their environment. On the other side are scientists, all funded by nonindustry sources, such as the National Science Foundation, who insist that atrazine is an EDC disruptor in frogs exposed to very small concentrations. The obvious social saturation of research into the effects of an agricultural chemical—the economic advantages of atrazine on the one hand, the environmental and public health threats on the other—increases the possible impact of the rhetorical kinetics of this controversy. I argue here that the incommensurability between the sides has less to do with scientific (paradigmatic, methodological) differences and more to do with competing economic and environmental interests. These interests, combined with considerable uncertainties involved in determining the impact of a compound in an ecosystem where impacts can be highly variable, have engendered incommensurable rhetorics that have failed to resolve the debate.

Conflicting scientific explanations, like those under examination here, may be, as Prelli (2005) argues, understood as “rhetorical problems of practical communication rather than as logical problems of formal translation” (p. 298). Once rhetorically constructed and construed, misalignments may be resolved or deepened, depending, to a great extent on how the various sides communicate with various audiences and with each other. Scholars in the rhetoric of science have produced optimistic readings of how scientific rhetoric may adjudicate scientific disagreements based on paradigmatic misalignments. Bazerman and De los Santos (2005) suggest that “the holders of alternative hierarchies and taxonomies find effective enough ways of communicating with each other to carry on their respective businesses, with the help of each other” (p. 427). Prelli notes that Kuhn suggests that incommensurate explanations may be mitigated by participants if their efforts involved “a shift away from abstract and formal problems and toward situated and substantive obstacles to effective inter-paradigmatic communication” (p. 298). In the atrazine wars, no such communication has emerged. As I demonstrate, the two sides “talk past” each other by criticizing or completely ignoring each other, and by presenting stunningly incommensurate rhetorical constructions of atrazine itself and its potential to harm. What is most surprising in this case is that the stunningly incommensurate rhetorical constructions can be deemed credible due to considerable scientific uncertainties that allow authors to construct their preferred version of the story of atrazine.

In the atrazine wars, scientific uncertainties that may justify incommensurate rhetorics may also mask the real conflicts of interest that could motivate particular constructions. Industry influence on U.S. health and environmental policy associated with agricultural chemicals has a long history that is beyond the scope of this study to summarize (see Boone et al., 2014; Rohr & McCoy, 2010b, for overviews). Conflicts of interest could lie behind industry-funded scientific authors’ rhetorical decisions about how to represent the product manufactured and sold by the company funding them. Numerous studies of tobacco science (see King, 2006, for a review) have demonstrated that the tobacco-funded scientists distorted or downplayed evidence of harm, cast doubt, or dismissed studies showing harm by emphasizing phrases like “sound science,” which is a code word used by many politically motivated groups to argue against everything from climate change science to the health impacts of coal-fired power plants (see Reeves, 2005). Another such phrase used by tobacco-funded scientists to question solid consensus about harm is “good epidemiological practice” (King, 2006, p. 1067). Deb (2005) compares the strategies of Syngenta-funded and tobacco industry–funded scientists, finding that Syngenta-funded authors “seem to intentionally create doubt about the validity of studies showing atrazine to be an EDC” (p. 408), just as tobacco-funded scientists attempted to create doubt about reports linking cigarette smoking and adverse health effects.

As I show below, industry-funded authors rhetorically construct atrazine as unlikely to harm and construct the scientific studies reporting harm as unconvincing or flawed. We also see in many cases the use of fact-like or high-certainty language in main conclusions within a scientific context in which considerable scientific uncertainties would preclude such language. However, we cannot so easily compare tobacco science and scientists with agricultural chemical science and scientists. Tobacco is a compound that individuals choose, and the harm, at least until second-hand smoke effects became known, was seen to be restricted to the smoker, so regulatory agencies did not impose on the tobacco industry–specific scientific protocols for testing effects. In contrast, all chemicals, because of potential impacts on nontarget organisms, are put through an Environmental Protection Agency (EPA) designated battery of tests designed to assess safety and effects at different dose responses and endpoints. So there is oversight of industry-funded science. As Freeman (personal communication, June 3, 2014), associate professor of environmental toxicology at Purdue University, who has served on EPA panels that develop new environmental toxicological protocols, explains, “the chemical companies certainly do not want to put out a chemical that's going to be clearly harmful. They want to know what new protocols they will need to follow and they know that they will be scrutinized.”[1]

Although King (2006) and Deb (2005) expose industry-funded scientists' machinations, they do not examine the larger community debates between industry and non-industry-funded scientists, who are well aware of conflicts of interest and the influence of industry on regulatory decisions and may attempt to counteract that influence through the rhetorical moves they make in their published research reports. As we see below, non-industry-funded authors rhetorically construct atrazine and the scientific studies reporting EDC effects in such a way that heightens atrazine as a risk. We also see, as with the industry-funded authors, the use of fact-like or high-certainty language in main conclusions within a scientific context in which considerable uncertainties would preclude such language.

In the atrazine wars, identifying a clear paradigm misalignment is difficult. The scientists involved in this debate, no matter what they report about atrazine, are environmental biologists and eco-toxicologists who conduct laboratory and field studies. Also journals such as *Aquatic Toxicology* and *Environmental Toxicology and Chemistry* and other similar journals published studies from both sides. Although some intellectual and procedural differences between traditional toxicology (with its focus on a chemical's effects on individual organisms and subindividual processes) and eco-toxicology (with its focus on quantifying effects on populations)[2] exist, those differences do not appear to be driving the incommensurate rhetorical constructions. These constructions of atrazine are incommensurate not so much because of any paradigmatic or methodological incommensurability but because of incommensurable rhetorical exigencies—the economic and the environmental.

Prelli (2005) maintains that commensurate communication can be achieved if participants "clarify situated ambiguities that are at the source of communicative confusion and conflict" (p. 299). In the case at hand, "situated ambiguities" are the real scientific complexities surrounding the nature of atrazine, its environmental fate, and the science investigating EDCs in an ecosystem. These "situated ambiguities" or complexities create an open space for scientific authors to construct a story of atrazine that best suits their agenda, to tell the story slant without committing blatant dishonesty. Michelle Boone, associate professor of zoology at Miami University in Oxford, Ohio, served on the 2012 EPA Science Advisory Panel reviewing the scientific literature on EDC effects of atrazine. For Boone, who has never been funded by industry, the scientific complexities make it "entirely possible for these two groups of scientists to be doing good science and reporting very different conclusions" (personal communication, May 5, 2014). This study contributes to our understanding of the relationship among scientific complexity, competing or incommensurable interests or exigencies, and scientific authors' rhetorical strategies. It also provides insight into those circumstances in which scientific authors' rhetorical constructions do more to prolong than to resolve scientific controversy. From here, I contextualize the atrazine wars with a discussion of atrazine itself, its economic impact, and the difficulties or situated ambiguities involved in determining its possible impacts in the environment. Then I report on an analysis of 49 studies of atrazine published between 2000 and 2013. I show that the incommensurable rhetorics we find only prolong rather than resolve controversy.

BACKGROUND ON ATRAZINE

Farmers have benefited from atrazine since it was first approved for sale in 1959. A selective, systemic herbicide, atrazine is inexpensive and effective at controlling the farmer's two principal curses besides the weather—broadleaf weeds and high production costs. Estimates of the total economic loss if atrazine and other triazines were banned vary considerably based on the baseline herbicide use patterns used, the investigative scope, whether regional or national, and the particular crop studied. In recent reviews of economic benefit studies, Carlson (2008) concludes that yields would drop 6%, with a $1.47 billion loss if atrazine were banned. However, Ackerman (2007) concludes that yields would likely drop only 1%, and farmers could actually benefit from an estimated 2% increase in corn prices that would result from lower yields (p. 448). An atrazine ban would perhaps put a greater dent in Syngenta's profits than it would in farmers'.

When it was first introduced, atrazine was a seemingly benign compound compared to the organophosphates and organichlorides Rachel Carson exposed in *Silent Spring*. Compared to those compounds, which can remain in the environment for decades and in the bones for a lifetime, atrazine's environmental fate is much shorter, from days to several months, depending upon environmental conditions. According to the Environmental Protection Agency's (EPA, 2005) fact sheet on atrazine, atrazine causes heart, lung, and kidney congestion and adrenal disruption and death in acute exposures, depending on the dose and body weight. Chronic exposure to atrazine by drinking tainted water, breathing its vapors or mishandling its application causes cardiovascular disease and reproductive problems. A few studies report that men working on farms that apply atrazine are at greater risk of infertility than the rest of the male population (Swan, 2006; Swan et al., 2003). And other studies report that pregnant women living in agricultural areas and drinking well water during the spring, when applications and concentrations spike, have a higher risk of delivering low-for-gestational-age infants (see Ochoa-Acuña, Frankenberger, Hahn, & Carbajo, 2009).

The EPA regulates atrazine and other agricultural pesticides through the Office of Water, which in 1991 set a limit on the average annual concentration in drinking water at 3 parts per billion (ppb) (EPA, "Basic Information," n.d.). This is above the World Health Organization's (2004) 2-ppb limit as well as the limit of 0.1-ppb set by the European Union before it banned sales of the chemical in 2003. Every six years, the EPA conducts a registration review of atrazine during which Scientific Advisory Panels (SAP), made up of scientists specialized in relevant areas who review the scientific literature, apply established experimental quality standards (EPA, "Pesticides," n.d.). A SAP's White Paper explains what the panel has determined is clear evidence of an effect and which studies have led to their conclusions. The EPA then decides whether to register the chemical and may not follow the SAP's recommendations, for reasons that are not discussed here (Boone, personal communication, May 5, 2014). SAP White Paper reviews in 2003 (EPA, White Paper, 2003) and 2007 (EPA, White Paper, 2007) did not register a clear determination that atrazine, in the levels it is typically found in the environment, threatened amphibians. Currently, another EPA SAP is reviewing atrazine's registration (EPA, 2012). The latest atrazine registration review, begun in 2012, has not yet been completed. The preliminary SAP (EPA, 2012) reviewed scientific students of atrazine, applying protocols and standards developed in the 2007 SAP. The 2012 SAP concluded that only one study, (Kloas et al., 2009) which was funded by Syngenta and which reported no negative effects of atrazine on amphibians, had met the research protocols and standards. Based on Kloas et al. alone, the EPA (2012) determined atrazine to be safe to amphibians in the environment. Michelle Boone, who served on that SAP, says that she and other panel members determined many studies showing effects had followed good experimental practices and were valid. Even though she does not question Kloas et al.'s scientific integrity, she is dismayed that the EPA based its conclusion about atrazine's effects on amphibians on only one study, one funded by industry (Boone, personal communication, May 5, 2014). Even though the science may be valid, "You end up with a conflict of interest because the research money is coming from industry" (Boone, personal communication, May 5, 2014). In a recent study (Boone et al., 2014), Boone and other scientists, including Jason Rohr, who was also interviewed for this study, argue that industry has too much influence on EPA policy regarding agricultural chemistries.

SCIENTIFIC COMPLEXITIES IN TOXICOLOGICAL RESEARCH

Significant scientific complexities, or in Prelli's (2005) terminology, "situated ambiguities," bear on the discourse we examine. One "situated ambiguity" concerns the actual concentrations of atrazine in the environment. In an interview with the author, ecologist Jason Rohr (2014), who is associate professor of integrative biology at the University of South Florida, said that ecologically relevant concentrations are about 400 ppb and below, with concentrations in freshwater streams range 100 and 200 ppb. But concentrations can range from 0 to 1,000 ppb depending on distance from application site and a plethora of environmental conditions. During the spring, when farmers are applying the chemical, concentrations in surface, ground, and drinking water can spike well above the EPA's standards, if only for days at a time (personal communication, May 13, 2014).

Another “situated ambiguity” concerns Atrazine's environmental fate—how long it remains active in soil and water. According to Rohr and McCoy (2010b), “atrazine is [environmentally] persistent relative to most current-use pesticides” (20). Yet multiple variables lead to wide disparities in persistence. Depending on soil composition and pH as well as rainfall and temperature, atrazine can remain in soils from 14 days to years (EPA, “Atrazine Chemical Summary,” n.d.). Depending on sunlight, climate, and the levels of acid and alkaline in the water, atrazine can persist in surface and ground water for longer than six months (EPA, “Atrazine Chemical Summary,” n.d.).

Another set of situated ambiguities concerns the science of endocrine disruption and toxicology. Determining whether atrazine or any compound in environmentally relevant concentrations, or sub-lethal, disrupts endocrine systems in amphibians is a far more complex matter than identifying its carcinogenicity. In cancer studies, no matter the animal, you have the same end points—cancerous tumors—but with endocrine disruption, there are numerous end points, many not so obvious or not even recognized yet as end points. End points can also differ from one animal to another as each animal or amphibian species has a different endocrine system and different developmental stages. And, unlike the linear responses in tobacco studies—the higher the concentration, the worse the effects—in EDC studies in amphibians, dose responses can be *U*-shaped, that is, there can be more effects at the lowest and highest doses than in the middle. Determining what concentrations will cause which effects after how much time exposed, in different species with different tolerance levels, is a complicated undertaking. As a result of the indeterminate nature of environmentally induced endocrine disruption, one would expect to find scientific authors using the language of uncertainty or at least qualifying their conclusions. This is not what I have found in many of the studies in our database, no matter whether they are reporting effects. There is a high tendency on both sides to state their conclusions with high or medium linguistic confidence, which I believe does not allow for the possibility of doubt and erases the potential for compromise and commensurate explanations.

These complexities, I argue, have allowed authors to select some features of atrazine while screening out others without committing conspicuous misrepresentation. According to an author of two of the papers in my database, Jennifer Freeman, associate professor of environmental toxicology at Purdue, “Whether authors give low or high estimates, they are both right” (personal communication, June 3, 2014). After collecting samples in several places in Illinois, Freeman's team found that concentrations “vary, where in some areas, we'd find less than a hundred ppb and in other places, we'd find 200 ppb” (personal communication, June 3, 2014).

Our story began in 2002 with research conducted in the laboratory of Tyrone Hayes, professor of integrative biology at the University of California, Berkeley. A few years before, Hayes had accepted funding from Syngenta to study the effects of atrazine on frogs, and when he and his colleagues discovered strong indication of EDC effects, he reported back to Syngenta who decided not to allow publication of the data. Hayes then secured funding from the National Science Foundation, eventually conducting both field and lab studies and publishing in *Nature* (Hayes, Haston, et al., 2002) and the *Proceedings of the National Academy of Science* (Hayes, Collins, et al., 2002). The authors reported serious endocrine-disrupting effects in frogs exposed to levels that had previously been considered safe, as low as 1 ppb of atrazine in water. The papers generated considerable attention in scientific news outlets as well as in the lay press (see Betts, 2002; Yoon, 2002). In response, Syngenta sent out press releases through scientists on its Ecorisk panel who attacked Hayes' work, mostly by claiming that his findings could not be replicated (see Betts, 2002; Yoon, 2002). Since 2002, several laboratories across the country, including the Hayes' laboratory, have contributed to a growing database of studies reporting EDC effects of atrazine on amphibians exposed to very low concentrations. At the same time, beginning in 2003, Syngenta-funded studies report no EDC effects.

Other than the obvious incommensurate conclusions, what rhetorical incommensurabilities can we identify in this division between industry-funded and non-industry-funded science? From here, I examine the ways that authors on both sides of the question make selections about what to emphasize and what to downplay, what to intensify, and what to dilute to direct readers' attention to a preferred construction of atrazine.

THE SCIENTIFIC LITERATURE DATABASE

Using ProQuest Biological Science Collection database, I selected studies published from 2000 to 2013 that addressed the question of whether atrazine (and other agricultural pesticides) inhibited development of amphibians in concentrations considered below the level of nonlethal effects (20 ppb). On the basis of their focus on atrazine and amphibian development, I selected 49 research reports and four literature reviews. Of these, 35, including three reviews, were authored by scientists funded by non-industry sources—the National Science Foundation, the NIH, and the like. All but four of these non-industry-funded studies report EDC effects. The remaining 14 were authored by scientists belonging to the Syngenta-funded Ecorisk panel. I read all of these papers carefully and created a data map based on the following text features:

Title type,

The statement of the main claim (last sentence of the abstract and repeated in the discussion),

Whether atrazine was termed a contaminant or pollutant,

Whether "drinking water" or "ground water" was mentioned,

The environmental concentration estimates given,

The environmental persistence estimates given,

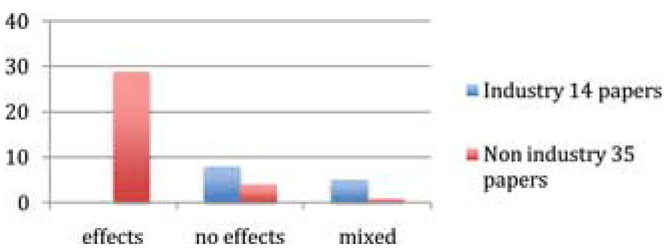
The studies cited in the literature review, and

Confidence levels in the language of key statements (statement of main claim, statements in the literature review).

In gaining a full understanding of this literature base, I also read the EPA SAP White Papers for atrazine registration reviews in 2003, 2007, and the first SAP meeting in 2012. These White Papers identified the flaws in the studies reviewed and further helped me understand the scientific complexities involved in identifying one compound as an environmental EDC. Finally, I interviewed scientists who published papers in my database and are familiar with the EPA's registration process.

Applying the analytical system outlined above to all 49 papers, I found incommensurate explanations of atrazine's possible effects on the reproductive systems of frogs that correlate to funding source. Industry-funded and non-industry-funded authors tend to employ a language that is more fact like, free of hedging terms, in key claim statements. Funding source also seems to explain diverging framing or characterizations of atrazine itself, with industry-funded authors downplaying and non-industry-funded authors intensifying the impression of potential harm. Finally, funding source also explains diverging characterizations of the research on atrazine, with industry-funded authors openly criticizing the studies reporting effects and non-industry-funded authors mostly ignoring industry-funded studies altogether. Figure 1 provides a breakdown of reported effects by funding source.

FIGURE 1 Of the 14 industry funded papers, 5 report some effects, yet they emphasize no effects in their conclusions. Of the 35 non-industry funded reports, all but 4 report effects while one study reports mixed effects.



Confidence Levels

Despite considerable uncertainties involved in determining any association between one compound in an environment and a particular effect, we find scientific authors on both sides of the controversy employing fact-like language to state their main claims. With such high stakes, a possible ban on a profitable chemical or the depletion of frog populations around the world, authors who report effects as well as those who do not convey high or medium confidence in their findings. What I have determined to be a high confidence or fact-like statement is one containing few or no qualifying phrases or hedging terms in concluding what atrazine does or does not do.

Here are examples of fact-like statements by funding source:

Non-industry-funded:

> Atrazine (^{3}0.1 ppb) *induced* hermaphroditism and demasculinized the larynges of exposed males (≥0.1 ppb). (Hayes, Collins, et al., 2002, p. 5476)

The statement is true to the manipulated factors in the study, but the verb *induced* implies causation more generally. Another feature of the "fact-like style" is a tendency to extract a broader statement about atrazine.

Here is such a statement from the same study:

> This widespread compound and other environmental endocrine disruptors may be a factor in global amphibian declines. (Hayes, Collins, et al., 2002, p. 5476)

Industry-funded:

Here are statements of two main findings from an industry-funded study (Carr et al., 2003). Notice that there are effects in one endpoint but no effects in the other:

> Exposure to either estradiaol or 25 ppb atrazine increased the incidence of intersex animals based on assessment of gonadal morphology. (p. 396)

> Atrazine did not reduce the size of the laryngeal dilaror muscle, a sexually dimorphic muscle in this species. (p. 396)

This broad statement from Carr et al. (2003) ignores their own finding of intersex and employs fact-like negative constructions:

> We conclude that environmentally relevant concentrations of Atrazine *do not influence* metamorphosis or sex rations and *do not inhibit* sexually dimorphic larynx growth in X. Laevis. (p. 396)

Carr et al. is one of the five industry-funded studies reporting EDC effects in some end points and no effects in others. However, all five of the studies conclude that atrazine is not an EDC in amphibians in low concentrations and qualify the effect in various ways.

The appearance of fact-like statements of main conclusions in a scientific field examining a new phenomenon is perhaps rare, especially in the early published studies and given the considerable uncertainties I have outlined. It is possible that the competing values—economics versus environmental protection—might have led authors to express a high degree of confidence in their findings. Nevertheless, Jennifer Freeman, interviewed for this paper and lead author of two papers in 2005, is critical of what she calls the “overstating and understating” of atrazine's EDC effects: “I think both sides are really at fault, in overstating and understating and creating this controversy when the true questions should be: is this causing an effect or not and let's do good scientific studies and figure it out” (Freeman, personal communication, June 3, 2014).

A pattern of dramatic and intense language can be found in the non-industry-funded studies authored by Tryone Hayes and his team at the Department of Integrative Biology at the University of California, Berkeley. In several papers, Hayes uses language that can be described as overstated and emotional (for scientific reports), with strong verbs suggesting atrazine's causative role and also highlighting the frog's suffering. Here are some examples:

> Male X. Iaevis suffered a 10-fold decrease in testosterone levels when exposed to 25 ppb atrazine. (Hayes, Collins, et al., 2002, p. 5476, emphasis added)

> Atrazine is a *potent* endocrine disruptor that both chemically castrates and feminizes male amphibians. (Hayes et al., 2006, p. 134, emphasis added)

Hayes attracted negative attention from Syngenta that led to a highly publicized conflict that is beyond the scope of this study to cover (see Aviv, 2014; Thomas, 2006, for reviews).

A medium confidence statement contains qualifying or hedging terms but nonetheless expresses confidence in the conclusion. Here are examples by funding source:

Non-industry-funded (medium confidence):

> Atrazine *was found to* alter the timing of metamorphosis of X. laevis using both nuclear analysis and gross morphology. The NF staging was found to be a sensitive assay to measure effects of development, whereas flow cytometry provided an impartial quantitative measure. (Freeman & Rayburn, 2005, p. 1648).

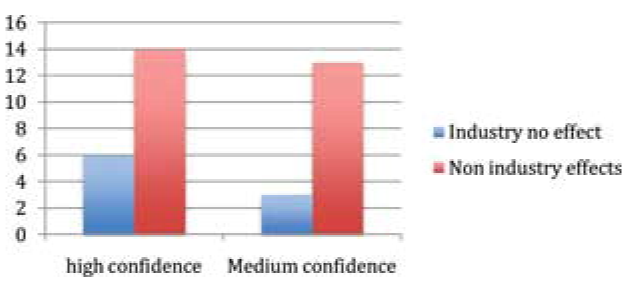
Industry-funded (medium confidence):

> Atrazine concentrations were *not significantly correlated* with the incidence of hermaphroditism, but maximum atrazine concentrations were correlated with TO incidence in juvenile frogs in 2003. (Murphy et al., 2006, p. 230)

Here Murphy et al. (2006) explain away the effects, testicular oocytes, they found, as "natural processes" (p. 230).

> However, given *the lack of a consistent relationship between atrazine concentrations and TO incidence*, it is *more likely* the TOs observed in this study result from natural processes in development rather than atrazine exposure (p. 230).

FIGURE 2 shows that most papers in the database present their conclusions with high or medium confidence. Of Industry-funded papers reporting no effects, six do so with high confidence, three with medium confidence. 14 non-industry-funded papers report effects with high confidence while 13 report with medium confidence.



The Language of Titles

Other language moves that increase the tenor of confidence can be found in titles. Harmon and Gross (2009) note that when authors nominalize actions in titles, they are staking claims (p. 458). Among non-industry-funded studies, we find a pattern of "claim-staking" (Harmon & Gross, pp. 458–460) titles in 19 of the 29 non-industry-funded studies reporting EDC effects. Titles emphasize atrazine's harmful effects or action upon amphibians. Here are some examples:

> Perturbation of Organogenesis by the Herbicide Atrazine in the Amphibian Xenopus laevis. (Lenkowski, Reed, Deininger, & McLaughlin, 2008, p. 223)

> Feminization of Male Frogs in the Wild: Water–borne herbicide threatens amphibian populations in parts of the United States. (Hayes, Haston, et al., 2002, p. 895)

> Hermaphroditic, Demasculinized Frogs after Exposure to the Herbicide Atrazine at Low Ecologically Relevant Doses (Hayes, Haston, et al., 2002, p. 5476).

Other titles employ more direct causal language:

> Atrazine is an Immune Disruptor in Adult Northern Leopard Frogs (Rana Pipiens) (Brodkin, Madhoun, Rameswaran, & Vatnick, 2007, p. 80).

> Atrazine induces complete feminization and chemical castration in male African clawed frogs (*Xenopus laevis*) (Hayes et al., 2010, p. 4612).

Considering the scientific uncertainties as well as the established consensus about atrazine's relative safety in low concentrations, these titles seem rather bold. Until that time, the no-observed-effect concentration was considered 200 ppb for larval growth and metamorphosis in various frog species (Allran & Karasov, 2001). A highly cited study (Solomon et al., 1996) had established that environmental concentrations of atrazine posed no threat to amphibians and also found that environmental concentrations rarely exceeded 20 ppb. Boone (personal communication, May 5, 2014) thinks that these titles overstate findings. The earliest titles perhaps were more egregiously bold because the science was so new, as she explains:

> Impacts on amphibian reproduction had not been examined [and because of a solid consensus] that non-target animals were not at risk to environmental concentrations of atrazine, with a lot of data to support that, to make such bold declarations was premature. (personal communication, May 5, 2014).

In contrast, industry-funded authors are more likely to employ what Harmon and Gross (2009) term “thematic titles” or those that “simply introduce the main theme” (p. 461) without claim-staking moves. All but one of the 16 papers are titled thematically, as in the following:

> Response of Larval Xenopus Laevis to Atrazine: Assessment of Growth, Metamorphosis, and Gonadal and Laryngeal Morphology.” (Carr et al., 2003, p. 396)

> Effects of atrazine on metamorphosis, growth, laryngeal and gonadal development, aromatase activity, and sex steroid concentrations in Xenopus laevis. (Coady et al. 2005, p. 160)

We can only speculate here about the motives behind the overwhelming use of thematic titles in these industry-funded papers. The thematic title may convey an impression of scientific objectivity, which may be of greater concern to authors who are reporting good news about a product sold by the company that has funded the research.

INCOMMENSURATE CHARACTERIZATIONS OF ATRAZINE

Characterizations of Atrazine's Potential to Harm

Atrazine is introduced in the abstracts and/or introductions to all of the studies examined. The industry-funded studies tend to downplay atrazine's potential to harm whereas the non-industry-funded studies tend to accentuate that potential. A neutral presentation is one that avoids either strategy.

Non-industry-funded authors tend to described atrazine as a “contaminant” or “pollutant” that is “widespread” or ubiquitous and emphasize that it is carried well beyond the application site. We also see non-industry-funded authors using the words *drinking water* or *ground water*. Here are some examples from non-industry-funded studies:

> Atrazine contamination is widespread and can be present in excess of 1.0 ppb even in precipitation and in areas where it is not used. (Hayes et al., 2003, p. 568)

> … the widespread use of atrazine has raised major concerns for a number of reasons including its presence in drinking water, links to cancer and Parkinson's disease in humans, and adverse effects on aquatic organisms. (Brodeur, Svartz, Perez-Coll, Marino, & Herkovits, 2009, p. 162)

Non-industry-funded authors are also more likely than industry-funded authors to emphasize that atrazine concentrations in the environment can be high. We see the phrase *as high as* used to convey the likelihood of atrazine exposure. Here are some examples:

> Atrazine has been reported at concentrations *as high as* 860 parts per billion (ppb) below field plots [2] and 1,000 ppb in tail water pits [3]. (Freeman & Rayburn, 2005, p. 1648, emphasis added)

> During storm events, concentrations of atrazine in tributaries in southern Ontario frequently exceeded levels known to cause endocrine disruption in aquatic species; historically levels *as high as* 95 [ppb] have been recorded in Ontario streams. (McDaniel et al., 2008, p. 231, emphasis added)

Industry-funded authors, on the other hand, tend to downplay atrazine as likely to be in the environment and likely to harm. None of these authors refers to atrazine as a contaminant or pollutant and none uses the words *drinking water* or *ground water* or refer to human health. Instead, industry-funded authors use the phrase *potential exposure* and soften the impact of atrazine's “frequent detection,” a common phrase, by reminding the audience that atrazine concentrations in the environment are low. Nine authors mention specific estimates of environmental concentrations of atrazine, and they all, in some way, emphasize that exposure is less likely due to low concentrations. Here, the authors place 20 ppb, which was the lowest effect level established by the EPA at the time, as the maximum concentration:

> As a result of both its widespread use and its persistence, atrazine has been widely detected in surface waters and rainfall with peak concentrations ranging up to approximately 20 [ppb]. (Hecker et al., 2004, p. 1996)

Here Murphy et al. (2006) offer a more realistic estimate of peak concentrations yet emphasize that such a concentration would be of short duration:

> Environmental concentrations of atrazine have been reported to usually not exceed 20 [ppb], except in small temporary puddles in fields where peak concentrations can be greater than 200 [ppb] for short periods of time after storm events” (p. 230).

Solomon et al. (2008) simply note that atrazine concentrations are diluted in the environment:

> Because of dilution in these environments, exposures are likely to be very small and do not present a direct or indirect risk. (Solomon et al., 2008, p. 725)

Environmental Persistence

How long atrazine persists in the environment is determined by multiple factors. Soil type and pH, the acidity and alkaline in water, sunlight, rainfall and other climate conditions lead to variability, from days to years in soil and from days to many months in water (EPA, “Atrazine Chemical Summary,” n.d.). Non-industry-funded authors, wishing to establish that atrazine is likely to contaminate ecosystems, are more likely than industry-funded authors to mention estimates of persistence or half-lives of atrazine in water and soil, and their estimates tend to be higher than more conservative estimates. Here are some examples:

> [Atrazine] can persist for decades after its use is halted. (Hayes et al., 2006, p. 134)

> Atrazine … can remain in soil for well over 6 months and in water for up to 1 year. (Olivier & Moon, 2010, p. 654)

In Lenkowski et al. (2008), all the characteristics likely to place atrazine in an ecosystem are heightened with adjectives:

> Atrazine also has a *high leaching potential*, as it is moderately hydrophilic with *high aqueous solubility*, and it *must be applied to crops multiple times* early in the growing season. As a result, *considerable concentrations* of atrazine and its metabolites in groundwater and surface runoff are of concern. (p. 223, emphasis added)

It is important to keep in mind that leaching and aqueous solubility vary according to a variety of conditions. It is also not always true that atrazine is applied multiple times early in the growing season. Application rates vary, depending upon multiple factors. Clearly, the authors intend to leave an impression with readers of atrazine's potential to harm.

Industry-funded authors mentioning persistence tend to present the more conservative or lowest ranges. Only two industry-funded authors mention atrazine's persistence, both selecting the estimates in the lower ranges. This author's estimate of soil half-life is much lower than the EPA's estimates of 14 dayds to years in soils and longer than six months in water (EPA, “Atrazine Chemical Summary,” n.d.):

> Atrazine has been found to have a half-life in soil of from 8 to 99 days, depending on soil and environmental conditions, while the half-life of atrazine in the aquatic environment ranges from 41 to 237 days. (Murphy et al., 2006, p. 231)

Murphy et al. (2006) qualify this statement with a reference to “a later study” finding “the half-life was only 38 days,” leading the authors to conclude that “atrazine can persist in the environment, albeit at relatively small concentrations” (p. 231).

To summarize, Figure 3 provides a breakdown of strategies used by non-industry-funded authors to intensify the impression of atrazine's harmfulness. Figure 4 provides a breakdown of strategies used by industry-funded authors to dilute the impression of atrazine's harmfulness.

FIGURE 3 Of the 34 non-industry-funded papers, 24 use some strategy to intensify the impression of atrazine's potential to harm. Twenty-one emphasize high concentrations whereas three emphasize low. Fifteen non-industry-funded papers mention persistence and of those; 14 emphasize longer duration, and only one emphasizes short duration. Fifteen papers mention groundwater and ten mention drinking water, with eight papers mentioning both. Two non-industry-funded papers employ all of the strategies emphasizing harm, whereas nine employ three of those strategies, and nine other papers employ two of them.

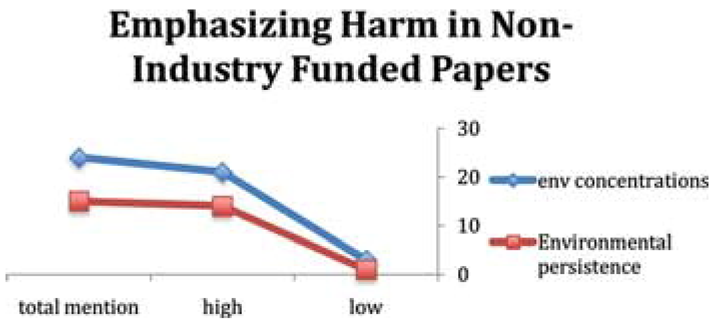
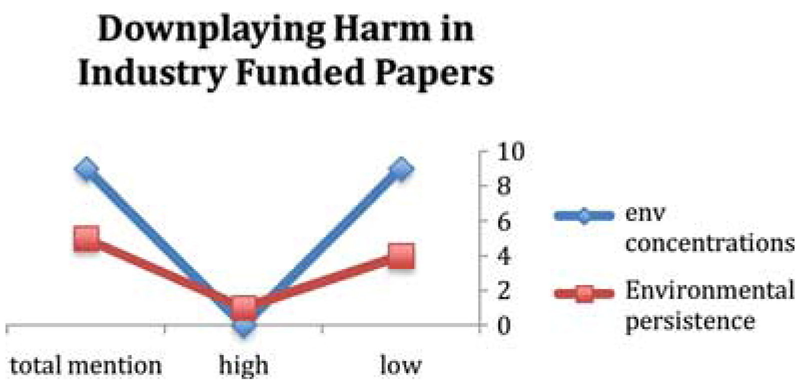


FIGURE 4 Of the total 15 industry-funded papers, authors who mention environmental concentrations and/or persistence emphasize low concentrations or short duration. None mention drinking water or ground water.



INCOMMENSURATE REVIEWS OF THE LITERATURE

When scientific authors, from both sides of the atrazine debate, review the relevant studies of atrazine's effects on amphibians, rarely do we see a balanced presentation of both sides. The dismissal of the opposition's findings or neglecting to review them altogether creates an appearance of scientific paradigmatic misalignments when the misalignments are more likely extra-scientific. Effective “commensurate” communication that might clarify and resolve points of disagreement is absent.

Text analysis of these literature reviews exposes striking differences in linguistic or rhetorical strategy between the two sides. When industry-funded papers include a review of the literature, they represent studies reporting effects as uncertain or controversial, while they represent studies reporting no effects as certain and noncontroversial. In contrast, non-industry-funded studies emphasize certainty and consensus about atrazine's EDC effects on frogs and, for the most part, do not review industry-funded research at all.

Industry-funded studies construct the reports of atrazine's EDC effects on frog sexual development as scientifically weak, as “conflicting,” “suggested,” or and/or “hypothesized.” The scientists reporting effects are represented as “attempting to” show an association and failing to do so. On the other hand, studies finding no effects—all Syngenta funded—are represented as offering the final verdict on the matter. In the first Syngenta-funded study reporting no effects (Carr et al., 2003), references to the published studies reporting effects suggest conflict among the reports, which was not the case: “There have been conflicting reports regarding the potential for atrazine to influence reproductive development in amphibians at environmentally relevant concentrations" (Carr et al., 2003, p. 396).

After briefly summarizing two studies in which "atrazine was reported to" affect frogs' sexual development, the authors cite another industry-funded study that found no effects, using language that implies greater certainty, "In contrast, a field study of cricket frogs in Illinois *found no correlation* between historical incidence of intersex and atrazine use" (p. 396).

Another paper (Hecker, Kim, et al., 2005) contains a typical characterization of authors reporting effects as having "attempted to link these responses with exposure to atrazine" (p. 384). However, the authors follow this statement with a much more definitive and unhedged summary of findings from industry-funded studies:

> However, other studies with juvenile X. laevis *have not found effects* on the size of the laryngeal dilator muscle, gonadal development … at *such low* atrazine concentrations. (p. 384)

Industry-funded authors tend to charge the non-industry-funded authors with failing to establish a causal relationship between atrazine and EDC effects, as do Coady et al. (2004):

> It has been suggested that atrazine may function as an endocrine disrupting chemical in amphibians at concentrations as little as 0.1 ug/L … (p. 942)
>
> However, a causal relationship between atrazine exposure and reproductive responses has not been established in these cases. (Coady et al., 2004, p. 942)

Dismissal of the studies reporting positive associations between atrazine and endocrine disruption may also be accomplished by noting the weaknesses in methods or the lack of routine protocols, as Carr et al. (2003) do here:

> Aside from the frog embryo teratogenesis assay-Xenopus (FETAX) procedure, which is limited to a 96-h exposure window immediately after fertilization, *there are no standardized approaches* to assessing developmental exposure effects on development in X. laevis. (p. 397, emphasis added)

Of course, if there are no standardized approaches, we might wonder how these authors were able to claim this so confidently, "We conclude that environmentally relevant concentrations of atrazine do not influence metamorphosis or sex ratios and do not inhibit sexually dimorphic larynx growth in X. Laevix" (Carr et al., 2003, p. 396). Again, such references to different methodological approaches are examples of rhetorical rather than actual paradigmatic differences between the two sides.

Subtle dismissal of the methods employed can be observed in Kloas et al. (2009), who qualify their statement that "atrazine has been reported to affect sexual development and gonadal differentiation" by adding that "*the results of different studies have been inconsistent* (p. 396). In another example, Spolyarich, Hyne, Wilson, Palmer, and Byrne (2010) emphasize that "*most recent laboratory studies* examining the effect of atrazine on anuran larval development at environmentally relevant concentrations" do not find atrazine affecting frog growth and development (pp. 807–808, emphasis added). They then cite two studies in which low concentrations of atrazine "reportedly feminized" male tadpoles, then add that these studies have not been corroborated (p. 807). These moves create an impression that either bad science or paradigmatic incommensurability is involved.

Finally, a 2008 review by members of the Ecorisk panel dismisses all of studies reporting effects and concludes that

> Based on a weight of evidence analysis of all of the data, the central theory that environmentally relevant concentrations of atrazine affect reproduction and/or reproductive development in fish, amphibians, and reptiles is not supported by the vast majority of observations. (Solomon et al., 2008, p. 722)

However, ecologist Jason Rohr, whose meta-analysis (Rohr & McCoy, 2010b) is now the most cited review of the literature, analyzed the Solomon et al. (2008) review and found that the authors "misrepresented at least 50 studies from the primary literature," with "122 inaccurate statements," and "97% of those statements benefiting Syngenta in that they supported the safety of atrazine" (personal communication, May 13, 2014). Dr. Rohr refrains from identifying motives: "I'm not going to go there. I just documented the errors and will let the public decide" (personal communication, May 13, 2014).

Non-industry-funded authors demonstrate strong conviction about the question of atrazine's endocrine-disrupting effects through their linguistic and rhetorical choices in the literature reviews. In the following example, Brodkin et al. (2007) review studies reporting effects in such a way as to represent several controversial issues—what concentrations lead to what effects and whether hermaphroditism is an abnormality caused by atrazine or a normal stage of frog development—as uncontroversial:

> In *Xenopus laevis* and *Rana pipiens*, atrazine exposure to concentrations of 0.1 ppb *causes endocrine disruption* manifested as gonadal abnormalities and hermaphroditism in males [6, 8] and thereby may disrupt their ability to reproduce. (p. 80, emphasis added)

We also find constructions of atrazine's endocrine-disrupting potential as black-boxed. Here endocrine disruption simply becomes one among a litany of adverse effects reported in the literature, "Laboratory and ecological field studies *have shown* that atrazine adversely affects multiple biological processes, including growth, metabolism, immune and endocrine system function, in several species of frogs and fish" (Langerveld, Celestine, Zaya, Mihalko, & Ide, 2009, p. 379, emphasis added).

When authors cite both sides, they either critique their opponents or they present a balanced review. Here, the funding source is identified followed by a criticism of the analytical method:

> 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. … However, none of the past reviews used a meta-analytical approach to identify generalities in responses to atrazine exposure. (Rohr & McCoy, 2010b, p. 20)

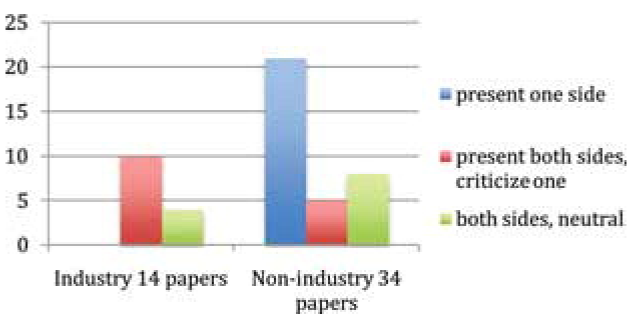
In a dramatic condemnation of the "influence of industry" as he calls it in a 2004 review, Hayes ("There is no denying," p. 1146) reviewed existing publishing literature and found that financial sponsorship was a “very strong predictor” of negative findings, with “100 percent of the negative studies funded by Syngenta” (p. 1146).

Non-industry-funded authors are more likely to ignore industry-funded studies altogether in their literature reviews. Among the 35 non-industry-funded studies, 22 of these papers ignore studies finding no effects and cite only those that do; five cite both sides but show they agree with studies finding effects—and criticize the Syngenta-funded studies—whereas seven offer a neutral presentation, showcasing the complexities and contradictory findings in an objective manner. One might make the same accusation that Deb (2005) makes about the critical intent of industry-funded authors: exclusion of non-industry-funded studies suggests a bias.

A balanced presentation has the potential to serve as the sort of commensurate communication that Prelli (2005) suggests might resolve controversies. Balanced literature reviews on the non-industry-funded side present the complexities and uncertainties that could explain the discrepancies from the two sides that should be resolved before the community can move on. Here is an example that is typical of the eight nonindustry studies with balanced reviews. Brodeur, Sassone, Hermida, and Godugnello (2013) first review the studies showing atrazine's effects on the immune system, its EDC effects, and effects on growth and reproduction. These matters, they suggest, are now matters of consensus. But they represent the question of whether atrazine alters tadpole growth and metamorphosis as unsettled: “reaching a conclusion remains difficult” (p. 11) because some studies report increases and some report decreases. They cite studies from the Ecorisk panel as well as other studies without dismissing any of them and attempt to find middle ground by offering an explanation that could bring the two sides together: a possible factor in these conflicting studies could be concentration-response curves, which are among the many complexities that the community will need to better understand.

Figure 5 illustrates these patterns of reference in the literature reviews of these papers.

FIGURE 5 Non-industry-funded authors (22) were more likely to review only those studies agreeing with the finding of effects and less likely to provide balanced coverage (eight). Although industry-funded authors always presented both sides, they were more likely (10) to criticize the opposition than to provide balanced and neutral coverage (four).



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CONCLUSION

Bazerman and De los Santos (2005) offer an optimistic analysis of how incommensurability was resolved between the field of toxicology and ecotoxicology. Yet, in the case of the atrazine wars, incommensurability has not been resolved, most likely because it derives from competing interests rather than competing paradigms. When it comes to regulation of a popular and profitable agricultural chemical, the clash between economic and environmental values leads back to an "appearance" of paradigmatic incommensurability effected by incommensurate rhetorics that prolong rather than resolve disputes.

That we have only the appearance of incommensurability can be suggestively supported if we look at how authors employ different conceptions of atrazine depending on their funding source. Two scholars, James Carr, an environmental toxicologist at Texas Tech University and Werner Kloas, an environmental toxicologist with the Department of Ecophysiology and Aquaculture in Germany, coauthored papers funded by Syngenta that constructed atrazine has unlikely to harm and dismissed studies offering evidence to the contrary (Carr et al., 2003; Kloas et al., 2009). Yet both scientists are coauthors on papers that were not funded by industry. Carr co-authored Orton, Carr, and Handy (2006) and Carr and Patino (2011), both papers reporting negative effects of atrazine. Kloas co-authored Orton, Lutz, Kloas and Routledge, (2009) which also reported negative effects. In these papers, which report finding EDC effects from low concentrations, atrazine is characterized as a harmful pollutant and as contributing to the global decline in frog populations. Because neither Carr nor Kloas was the lead author on these papers, we could argue that they had little control in rhetorical decisions. However, all authors of scientific research reports have a chance to review papers before publication and the opportunity to request revisions. It is likely that, since these studies had no connection to Syngenta, Carr and Kloas lacked the economic motivation to downplay atrazine's potential to harm.

As for the non-industry-funded authors, with no incentive to protect industry profits, we might well imagine that they are simply motivated by concern for the environment, so much that they are as inclined to exploit the resources of rhetorical emphasis as are the industry-funded authors. That 22 of 34 non-industry-funded papers cite only studies finding effects, completely ignoring the Syngenta--funded studies finding no effects, might indicate that non-industry-funded scientists were skeptical of industry-funded science (see Hayes et al., 2006; Rohr & McCoy, 2010a) and wished to demonstrate that skepticism through total dismissal. Or perhaps the value of environmental protection was in the background of their choices. Boone (personal communication, May 5, 2014) suggests that "cases like atrazine could be exceptions [to the rule of always being rhetorically cautious] because you have industry-funded authors attacking non-industry-funded authors, which could influence the way non-industry-funded authors respond."

This study should motivate scholars of technical communication to examine other instances of how scientific complexity and uncertainty, combined with conflicting priorities and interests, may engender incommensurable rhetorical constructions. Future research should examine, for example, incommensurate explanations in Bisphenol-A research, as this topic was mentioned by all scientists interviewed here as a case in which a conflict between industry and public health have stalled scientific consensus and sound policy.

Notes

1. All industry-funded authors were contacted with requests for interviews, but none responded.
2. I am grateful to Jason Rohr, Associate Professor, Department of Integrative Biology, The University of South Florida, who explained the disciplinary differences between traditional toxicology and eco-toxicology to me.

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