DDT IN USA

Wicked Problems: Chemical Insecticides and Environmental Health in the United States

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Abstract

In 1962, Rachel Carson published *Silent Spring* to wide acclaim. Carson's book alerted Americans to the dangers of chemical insecticides and herbicides to humans, wildlife and ecosystems. Late in 1972, after numerous hearings and a lawsuit, the U.S. Environmental Protection Agency banned DDT for non-emergency uses. The U.S. Congress also passed the Federal Environmental Pesticides Control Act (FEPCA) that same year. Environmentalists hailed the DDT ban as a major achievement. Many consider the ban and federal legislation to be watersheds in the history of environmental health in the United States. However, even well-intentioned legislation can have unintended consequences. Following the DDT ban, farmers became dependent on the highly toxic organophosphate insecticides. Thus, since the early Twentieth Century, chemical insecticides present a case study in "wicked problems".
Keywords: Rachel Carson, Chemical Insecticides, Environmental Health, USA

Résumé

« Problèmes pernicieux » : insecticides chimiques et santé environnementale aux États-Unis

En 1962, Rachel Carson a publié Printemps silencieux qui a été largement salué. Le livre de Carson alertait les Américains sur les dangers des insecticides et herbicides chimiques pour les humains, la faune et les écosystèmes. À la fin de 1972, après de nombreuses enquêtes et un procès, l'Agence américaine de protection de l'environnement a interdit le DDT pour les utilisations non essentielles. Le Congrès américain a également adopté la même année la loi fédérale sur le contrôle des pesticides environnementaux (FEPCA). Les écologistes ont salué l'interdiction du DDT comme une réalisation majeure. Nombreux sont ceux qui considèrent l'interdiction et la législation fédérale comme des tournants dans l'histoire de la santé environnementale aux États-Unis. Cependant, même une législation bien intentionnée peut avoir des conséquences inattendues. Après l'interdiction du DDT, les agriculteurs sont devenus dépendants des insecticides organophosphorés hautement toxiques. Ainsi, depuis le début du XX^{e} siècle, les insecticides chimiques constituent une étude de cas de « problèmes pernicieux ».
Mots-clés : *Rachel Carson, insecticides chimiques, santé environnementale*

In 1962, Rachel Carson published *Silent Spring* to wide acclaim. Carson's book alerted Americans to the dangers of chemical insecticides and herbicides to humans, wildlife and ecosystems. Late in 1972, after numerous hearings and a lawsuit, the U.S. Environmental Protection Agency banned DDT, an organochlorine insecticide, for non-emergency uses (e.g., agricultural applications as opposed to "emergency uses" in public health). The U.S. Congress also passed the Federal Environmental Pesticides Control Act (FEPCA) that same year. Environmentalists hailed the DDT ban as a major achievement. Many consider the ban and federal legislation to be watersheds in the history of environmental health in the United States. However, even well-intentioned legislation can have unintended consequences. Across the 20th Century, chemical insecticides present a case study in wicked problems. The term "wicked problems" refers to a class of social system problems where many clients and decision makers have conflicting values, and the ramifications in the whole system are thoroughly confusing. Proposed "solutions" often turn out to be worse than the symptoms.[1] The pattern of insecticide development, deployment and regulation constituted a never-ending series of wicked problems for more than a century. Though farmers (and chemical corporations) have shifted from one class of pesticides to another over time, the pattern has remained in force. I begin this paper by describing the synthesis of organophosphate insecticides to frame the history of pesticides as a wicked problem. I then examine Rachel Carson's *Silent Spring* to demonstrate how Carson captured the diversity of agricultural chemicals including chlorinated hydrocarbons and organophosphates, as well as the wide array of threats these products posed to ecosystems, wildlife and humans. I subsequently show how the legal and legislative focus narrowed the concern to DDT. Finally, I consider the pesticides that farmers adopted in the aftermath of *Silent Spring* and the risks these pesticides have to wildlife and humans.

Synthesizing Organophosphate Chemicals

The organic phosphate (later called organophosphate) insecticides - most of them esters of phosphorous acid - were first developed by German chemists who studied them from1936 onwards in the plant protection laboratory of Farbenfabriken Bayer at Wuppertal-Elberfeld. Gerhard Schrader, a leading chemist at Farbenfabriken Bayer, had the task of developing insecticides, concentrating his research on organophosphates.[2] Between 1938 and 1942, Schrader and his colleagues developed several organophosphate insecticides including HETP ("Bladan"), TEPP, and Parathion (E 605). After the British and American Technical Intelligence Committee interrogated Schrader and his coworkers in the immediate aftermath of World War II, the German knowledge about the properties of organophosphorus compounds reached the U.S.[3] The Toxicity Laboratory (hereafter referred to as Tox Lab) at the University of Chicago was one of the first sites to test organophosphates.[4] The U.S. was considerably interested in these new insecticides because they allegedly controlled aphids, against which DDT was proving ineffective. Tox Lab scientists including Kenneth Dubois and John Doull

1 West Churchman C. Free for All, *Management Science,* 1967, 14(4): B-141-B-146. https://doi.org/10.1287/mnsc.14.4.B141 accessed on April 29, 2022.

2 Schrader G. *Development of insecticides*. B.I.O.S. Final Report 714, London, 1946. On I.G. Farben, see also Tucker JB. *War of Nerves: Chemical Warfare from World War I to Al-Quaeda*, New York: Pantheon Books, 2006:24-41.

3 Schrader G. *Development of Insecticides…, op. cit.*

4 Doull J. Toxicology Comes of Age. *Annual Review of Pharmacology and Toxicology*, 2001, 41: 2-3.

evaluated parathion, which Schrader first synthesized in 1944 as E 605. American Cyanamid released the chemical as parathion. DuBois and Doull determined the median lethal dose (LD_{50}) of parathion to be less than 20 mg/kg in all species (rats, mice, cats, and dogs), which meant that parathion had the highest toxicity to mammals of any pesticide ever released. Like HETP, the Tox Lab researchers showed parathion to be a strong inhibitor of cholinesterase. A picture of consistency within the class of organic phosphate insecticides gradually emerged from toxicological assessments.[5]

Rachel Carson's Hierarchy of Insecticides

Rachel Carson, a biologist and science writer, first published *Silent Spring* as an article for *The New Yorker*, spread across three issues in May 1962 (Fig. 1). The book followed in fall of the same year. In *Silent Spring*, Carson established a hierarchy of dangerous insecticides. She first addressed the chlorinated hydrocarbons, starting with DDT, and progressively described other chemicals in the class, including chlordane, heptachlor, dieldrin, aldrin and endrin. Carson noted that DDT could travel through links of the food chain. For example, she observed that the chemical could be passed from sprayed alfalfa fields to chicken meal to hens producing eggs that contain DDT, or from hay to dairy cows whose milk contained 3 ppm of DDT, which could rise to 65 ppm in butter! Moreover, Carson noted that DDT could pass from mother to offspring, which meant that breast-fed infants could build up toxic chemicals in their bodies. Chlorinated hydrocarbons like DDT had already been shown to cross the supposed barrier of the placenta, so infants could likewise be exposed to chemicals in the womb. Carson cited the FDA declaration from 1950 that it was "extremely likely the potential hazard of DDT has been underestimated." She reflected on this as follows: "There has been no such parallel situation in medical history. No one yet knows what the ultimate consequences may be."[6]

Fig. 1 Rachel Carson photograph by Richard Hartmann © Courtesy of Magnum Photos

However, for Carson, DDT was just one chlorinated hydrocarbon, a large class of commonly used chemicals that mostly carry much higher toxicities than DDT. Chlordane, for example, had all the unpleasant attributes of DDT including the tendency to accumulate in soil, on food, and surfaces where it was applied. Carson cited Arnold Lehman, a pharmacologist at the Food and Drug Administration, who described chlordane as "one of the most toxic of insecticides—anyone handling it could be poisoned."[7] The toxicity of chlordane was so high that one victim developed symptoms and died

5 See Davis F R. *Banned: A History of Pesticides and the Science of Toxicology*. New Haven: Yale University Press, 2014.

6 Quoted in Carson R. *Silent Spring*. Boston: Houghton Mifflin Company, 1962: 23.

7 *Ibid.*: 24.

within 40 minutes of spilling a 25% solution on the skin. Heptachlor is one of the components of chlordane, but it was also marketed separately. Carson noted it had very high tendency to store in fat (i.e, it was lipophilic). Furthermore, she wrote, heptachlor had a tendency to convert to heptachlor epoxide in soil and the tissues of plants and animals; this compound was even more toxic than heptachlor, which was already four times more toxic than chlordane.

Even within her description of chlorinated hydrocarbons, Carson marked a group of chemicals for special distinction. She called these the chlorinated naphthalenes: dieldrin, aldrin and endrin. These chemicals were associated with illness and death in cattle and workers in electrical industries. In the case of dieldrin, Carson distinguished toxicity resulting from ingestion (five times more toxic than DDT) and dermal absorption (40 times more toxic than DDT). Carson called aldrin "the alter ego of dieldrin": despite its status as a separate entity, any application of aldrin left dieldrin residues behind in both soil and living tissues. Carson also noted many cases of occupational poisonings in connection with industrial handling of aldrin. Carson's discussion of aldrin introduced the specter of sterility in birds and mammals alike. Finally, she introduced endrin, "the most toxic of all the chlorinated hydrocarbons." Ever precise, Carson noted that despite having a chemical structure similar to dieldrin, the molecular structure of endrin rendered it five times as poisonous. Relative to DDT, "the progenitor of this group of insecticides," endrin was 15 times as poisonous to mammals, 30 times as poisonous to fish, and approximately 300 times as poisonous to birds. Such extraordinary toxicity led to die-offs of large numbers of fish and fatal poisonings of cattle that encountered sprayed orchards and even poisoned wells.[8]

Thus, Carson wove together details about the toxicity of chlorinated hydrocarbons for mammals, birds and fish. In just a few pages, she introduced concepts such as the passage of chemicals from mother to offspring via breast milk, bioaccumulation, lipophilicity (the bonding of chemicals to fats), residues in food and liver toxicity, even at the residual levels found in food. Nevertheless, Carson did not believe that chlorinated hydrocarbons posed the greatest threat to humans and wildlife: she had yet to address the organic phosphates.

Carson left no doubt where organic phosphates stood in the hierarchy of insecticides: "The second major group of insecticides, the alkyl or organic phosphates, are <u>among the most poisonous chemicals in the world</u>."[9] She proceeded to ironically describe the development of organic phosphates as nerve gases during World War II and the incidental discovery of insecticidal properties. However, it is her powerful description of the major effect of the organic phosphates on organisms that set her account apart from previous reports: "The organic phosphorous insecticides act on the living organism in a peculiar way. They have the ability to destroy enzymes, enzymes that perform necessary functions in the body. Their target is the nervous system, whether the victim is an insect or a warm-blooded animal."[10]

Aware that her subject demanded precision, Carson described the normal function of the central nervous system in detail, noting that excess acetylcholine presented a real threat to organisms. Her elegant description of cholinesterase inhibition was both vivid and technically precise. Carson elucidated the relation between the symptomology of cholinesterase inhibition and the normal function of the nervous system, and suggested that repeated exposures could lower a subject's cholinesterase level and leave him or her vulnerable to acute poisoning.[11]

But what was the risk to people who were not exposed on a regular basis? Carson answered this question with additional data showing that seven million pounds of parathion were applied in the United States each year and the amount used on Californian farms alone could "provide a lethal dose

8 *Ibid.*: 26-27.

9 *Ibid.*: 27. Emphasis added.

10 *Ibid.*: 28.

11 *Ibid.*: 28-29.

for 5 to 10 times the whole world's population."[12] What saved the people of the world was the rapid rate at which the organic phosphorous chemicals decomposed. Compared to chlorinated hydrocarbons, organophosphorus chemicals were quicker to break down into harmless components when in contact with water or even moisture, and their residues disappeared more rapidly. Yet even the relatively small quantities that remained posed a real threat: "The grove had been sprayed with parathion some two and a half weeks earlier; the residues that reduced [eleven out of thirty men picking oranges] to retching, half-blind, semi-conscious misery were sixteen to nineteen days old."[13] Carson noted that similar residues had been found in orange peels six months after the trees had been treated with standard doses.

Not even malathion, the least toxic of the organophosphate insecticides, escaped Carson's perceptive analysis. Malathion, according to Carson, was almost as familiar to the public as DDT. It was used in gardens, household insecticides and mosquito spraying. Carson revealed that nearly a million acres of Florida communities had been sprayed with malathion in an attempt to control the screw-worm. She questioned the widespread assumption that malathion could be used freely and without harm: "Malathion is 'safe' only because the mammalian liver, an organ with extraordinary protective powers, renders it relatively harmless. The detoxification is accomplished by one of the enzymes of the liver. If, however, something destroys this enzyme or interferes with its action, the person exposed to malathion receives the full force of the poison."[14] Citing research on potentiation by the FDA and Kenneth DuBois, Carson explained that the synergy between two organophosphorous chemicals could significantly exacerbate the effects of either or both (potentiation). Moreover, Carson cited evidence that potentiation was not limited to the organic phosphates. Parathion and malathion intensified the toxicity of certain muscle relaxants and others (malathion included) dramatically increased the effect of barbiturates.

Carson stressed that the advantages that organophosphates possessed over the chlorinated hydrocarbons, such as rapid decomposition, were significantly offset by the dangers of cholinesterase inhibition and potentiation. Her remarks on the acute toxicity of the various pesticides were only a preamble to her wider case, namely the long-term risks of pesticides (particularly chlorinated hydrocarbons) for landscapes, wildlife, and humans. In the remainder of *Silent Spring*, the subject of organophosphate insecticides recedes to the background. Although Carson thoroughly documented and dramatized the lingering damage to soil, water, flora and fauna associated with chlorinated hydrocarbons, her research revealed few such problems with organophosphates. Carson located one stunning example in which 65,000 blackbirds died after they were sprayed with parathion. She was most concerned, however, about unintended effects on humans such as farm workers and children.

It is clear that Carson believed that the organophosphates posed an equivalent, if not greater risk to wildlife and humans than the chlorinated hydrocarbons. No one would accuse Carson of oversimplification or reductionism. Only the most dedicated reader could keep track of the dizzying number of different insecticides (despite Carson's careful division of insecticides into two major classes, as described).

12 *Ibid.:* 30.

13 *Ibid.*

14 *Ibid.*:31.

Fallout of Silent Spring

According to Carson, no one chemical insecticide offered a genuine solution. Historians and biographers have analyzed the dramatic response to *Silent Spring* by consumers, scientists, industry representatives and legislators.[15] For the most part, the response to *Silent Spring* split along predictable lines. Carson found her greatest support from environmental activists such as Roland Clement, who presented the chief arguments of the book in many presentations to the public and various branches of government. Predictably, chemical companies mounted a savage campaign to discredit Carson and the claims she made in *Silent Spring*. One even threatened to bring suit against *The New Yorker* after Carson's articles appeared; William Shawn, long-time editor, apparently relished the possibility of unexpected publicity for the magazine. Still, some apparently impartial environmental scientists distanced themselves by criticizing some of Carson's interpretations of the evidence of environmental and human health hazard. One wrote that *Silent Spring* was "filled with truths, half-truths, and untruths."[16] But it would be an understatement to say that the public was roused from its complacency with regard to chemical insecticides. Such concerns reached the highest office in federal government when the U.S. President John F. Kennedy directed the President's Scientific Advisory Committee (PSAC) to review hazards of pesticides.

With the publication of *Silent Spring* and subsequent publicity including a nationally broadcast news program, the public discovered the risks of synthetic insecticides as well as the science of toxicology. *Silent Spring* and the ensuing public outcry inspired further study at the federal level, first by the President's Science Advisory Committee and then the Congressional Committee on Interagency Coordination. As in other hearings, few questioned the considerable benefits of pesticides and most witnesses couched evaluations of risks in light of benefits. Most witnesses, including Carson herself, acknowledged the considerable dangers associated with organophosphates. Scientists from the USDA, the FDA, and the University of Chicago Toxicity Laboratory presented their findings regarding organophosphates, the no-effect level and potentiation (which was most common among organophosphates). In an attempt to defend their safety record, several representatives of the chemical industry presented the multistage and multiyear process implemented by a company to identify, test and market a new insecticide, during which literally thousands of chemicals were winnowed down to a handful. With a sharper picture of toxicological risk presented in layman's terms in *Silent Spring* and thoroughly analyzed by the PSAC and Congress, the pathway to further regulation appeared clear.

However, neither the passage of the U.S. National Environmental Policy Act (January 1, 1970) nor the establishment of the Environmental Protection Agency in October 1970 ended the battle against DDT. The Environmental Defense Fund (EDF) returned to court, bringing suit against the EPA in *EDF v. Ruckelshaus*, in which EDF sought review of the failure to cancel the registration of DDT and to stop its use during cancellation hearings. During the course of this case, EDF strengthened its case sufficiently to compel significant action against DDT by the EPA. The judge in this new case and two colleagues ordered William Ruckelshaus, the EPA Administrator, to end all uses of DDT immediately. Ruckelshaus initially complied, then refused to suspend registrations after a sixty-day review. In June of 1972, after yet another lengthy hearing, Ruckelshaus banned the remaining uses of DDT on crops. However, he did allow for it to be used in cases of urgent public health such as emergency quarantine. He also allowed for it to be manufactured for exportation. More than a decade had passed since Carson alerted Americans to the environmental and health risks of synthetic insecticides. Most of the

[15] See Lear L. *Rachel Carson*: *Witness for Nature*,.New York: Henry Holt and Co, 1998; Lytle MH. *The Gentle Subversive: Rachel Carson, Silent Spring, and the Rise of the Environmental Movement.* Oxford: OUP, 2007; Dunlap T. *DDT: Scientists, Citizens, and Public Policy,* Princeton: Princeton University Press, 1981; Dunlap T. *DDT, Silent Spring, and the Rise of Environmentalism: Classic Texts.* Seattle: University of Washington Press, 2008. See also Davis FR, *Banned..., op. cit.*

[16] Cited in Dunlap T. *DDT. Silent Spring..., op. cit.*

legislative effort during the years leading up to the ban on DDT concentrated on persistent chlorinated hydrocarbons. The extensive toxicological research on organophosphates, Carson's significant concern regarding wildlife and human health effects and the extensive testimony in hearings at the federal level went unheeded, partly because the chemical industry was not yet able to provide suitable replacements for the organophosphate compounds.

It is also possible that the preoccupation with cancer as the predominant toxicological concern of pesticide risk assessment at the EPA and the FDA diverted regulatory attention from other forms of toxicity.[17] For the most part, organophosphate insecticides were not associated with carcinogenicity, so they were unaffected by screening methods that placed the regulatory emphasis on cancer. Since they typically did not bioaccumulate in the environment and were not persistent, they avoided one of the chief drawbacks of organochlorines. Lost in these toxicological analyses was the direct threat organophosphate insecticides posed to humans and wildlife in the form of acute toxicity. With the exception of malathion, organophosphates were moderately to highly toxic to humans and wildlife, especially birds, fish, aquatic organisms and non-target insects including bees. Thus, to a degree that would have shocked and disappointed Carson, the "other road"[18] was flooded with highly toxic organophosphate insecticides, which she had identified as some of the most toxic chemicals known to mankind.

With the DDT ban, Kenneth DuBois at the University of Chicago Tox Lab worried that farmers and public health officials would turn to organophosphates to control insects, thereby exposing farm workers and others to extremely toxic chemicals. His fear, shared by Carson and others, proved to be founded: organophosphate insecticides replaced DDT for many general uses. Between 1964 and 1994, annual pesticide usage in the United States doubled from 500 million pounds to over one billion pounds.[19] Most of the pesticides in use through the 1990s were organophosphates. Wildlife continued to perish at phenomenal rates, largely through exposure to organophosphates. In 1997, *Audubon* magazine reported that more than 67 million birds were dying annually as a result of pesticide poisoning in the United States.[20] As DuBois predicted, urban and suburban use of pesticides put humans and wildlife seriously at risk. Until its ban took effect in 2001, Americans used six million pounds of the organophosphate insecticide Diazinon annually, seventy percent of which was used by homeowners and professional applicators for structural and lawn pest control around residences and public buildings. An EPA database attributed 300 incidents of wildlife mortality (mainly birds) to Diazinon.[21]

As Linda Nash argued, farm workers regularly faced exposures to these substances, in violation of state and federal regulations and at levels that can inhibit cholinesterase.[22] John Wargo noted that the other high risk group was children, who typically consumed large amounts of the liquids, fruits and vegetables that may have carried organophosphates. Children may also have encountered organophosphates applied indoors.[23] Animal studies continue to sharpen scientists' understanding of the risks posed by organophosphates.[24] For example, there is substantial toxicological evidence that

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17 See a later report that concluded that acute toxicity was the primary hazard of pesticide exposures and that no pesticides had been proven to be carcinogenic, despite evidence of carcinogenicity in animals. See Cancer risk of pesticides in agricultural workers. Council on Scientific Affairs, *JAMA*, 1988 Aug 19;260(7):959-66.

18 The title and introduction to Chapter 17 "The Other Road" referenced the poem "The Road not Taken" (1916) by Robert Frost.

19 See Wargo J. *Our Children's Toxic Legacy*. New Haven: Yale University Press, 1996.

20 Bourne J. Buggin Out: Integrated Pest Management uses natural solutions both old and new to help farmers kick the chemical habit. *Audubon*, 1999, 101: 73.

21 Anon. *Diazinon. Chemical Watch Factsheet.* Washington DC: Beyond Pesticides, 2000.

22 Nash L. *Inescapable Ecologies: A History of Environment, Disease, and Knowledge.* Berkeley: University of California Press, 2006.

23 Wargo J. *Our Children's Toxic…, op. cit*.

24 Schettler T *et al. Generations at Risk: Reproductive Health and the Environment*, Cambridge, MA: MIT Press, 1999.

repeated low-level exposure to organophosphate pesticides may affect neurodevelopment and growth in developing animals.[25] During the 1980s and 1990s, there may have been as many as ten thousand cases of organophosphate poisoning annually in the United States alone. Yet another factor adding to the danger of accidental poisoning as a result of exposure to organophosphates is the association of the chemicals with suicide cases.[26]

In 1996, President Bill Clinton signed the Food Quality Protection Act (FQPA), which amended the Federal Insecticide Fungicide and Rodenticide Act (1947) and the Federal Food, Drug and Cosmetic Act (1938). FQPA required the EPA to reassess all food tolerances established before 3 August 1996, giving priority to those pesticides posing the greatest risk. This act compelled the EPA to conduct an extensive Cumulative Risk Assessment of organophosphates, resulting in registration cancellations of 14 organophosphates including methyl parathion, ethyl parathion, diazinon, and chlorpyrifos.[27]. Global use of insecticides tends to be much more difficult to track. Producers are not necessarily obligated to detail the use in each country and many countries lack governmental regulation. In 1990, a World Health Organization report on pesticides in agriculture predicted an increase in the use of organophosphates.[28] In fact, recent trends research suggests that use of chlorinated hydrocarbons has increased mainly as a result of residual (household) spraying in Southeast Asia and, to a lesser extent, in Africa. Although organophosphates dominated agriculture and vector control throughout the 1990s, the use of these chemicals dropped considerably after the release of the EPA's cumulative risk assessment. According to a 2011 World Health Organization report, global organophosphate use fell between 2000 and 2001 by more than an order of magnitude (from 5,792 tonnes to 477 tonnes).

Historians on DDT

Given the diversity of chemical insecticides and the comparatively low toxicity of DDT, it may seem strange that the legal and legislative response to pesticides focused on DDT. It is not difficult to imagine another scenario in which litigators and legislators focused their efforts on the insecticides that carried the greatest toxicities and worked towards less dangerous ones. Organophosphates would certainly be high on such a list, since most of them carried toxicities that were significantly greater than that of DDT (and indeed most of the other chlorinated hydrocarbons, for that matter). However, as we have seen, after litigation in New York, Michigan, and Wisconsin, the newly established Environmental Protection Agency refused to re-register banned DDT, in effect, for uses in the United States. The question remains: "Why DDT?" I learned from a former senior EPA official that the general view at the agency was that DDT offered low-hanging fruit, so to speak. Since it was released without patent, i.e., it was "nonproprietary," many chemical companies developed thousands of formulations containing DDT. For this reason, banning DDT distributed the burden across numerous chemical companies. By contrast, banning proprietary insecticides, i.e. those sold by one or two corporations, placed great economic burden on specific chemical corporations. Most of the organophosphates were proprietary. Having said that, and as we have seen, DDT was a significant environmental contaminant, and its ban produced long-term results in the recovery of populations of bald eagles, peregrines, ospreys and brown pelicans. There is therefore no doubt that the DDT ban was a major success of the American environmental movement. That said, did the DDT ban solve the pesticides problem in the U.S. and beyond?

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25 Eskenazi B, Bradman A, Castorina R, Exposures of children to organophosphate pesticides and their potential adverse health effects. *Environmental Health Perspectives,* 1999, 107, Suppl. 3: 409-419.

26 Freire C, Koifman S. Pesticides, depression and suicide: A systematic review of the epidemiological evidence. *International Journal of Hygiene and Environmental Health*, 2013, 216: 445-60.

27 Chlorpyrifos is an organophosphate registered by Dow Chemical in 1965.

28 World Health Organization. *Public health impact of pesticides used in agriculture*. Geneva: WHO, 1996.

Before we answer that question, we must turn to one of the most widely disseminated and read historical accounts of *Silent Spring* and DDT, namely *Merchants of Doubt* by Naomi Oreskes and Erik M. Conway. In the final chapter of the book, "Denial Rides Again: The Revisionist Attack on Rachel Carson," Oreskes and Conway note that Carson is an American hero. The first paragraph proceeds to list the relevant key words: pesticides accumulating in the food chain, damaging the natural environment, threats to bald eagles, malicious misogynistic attacks, affirmation by the President's Scientific Advisory Council, and finally DDT banned by EPA in 1972. The authors then describe the exception for public health uses of DDT, for example by the World Health Organization in the fight against malaria, concluding: "It was sensible policy, based on solid science."[29] Next, the authors fast forward to 2007 and the spate of reports from such organizations as the Competitive Enterprise Institute, the Cato Institute, and the Heartland Institute, all of which suggest that Rachel Carson was responsible for millions of deaths that occurred in Africa in the aftermath of the DDT ban. In decisively contradicting this claim, Oreskes and Conway defended Carson's claims in *Silent Spring* and the subsequent DDT ban. Nevertheless, by focusing almost exclusively on DDT, they also accepted the highly restrictive view of chemical insecticides as established by Carson's detractors.

Oreskes and Conway's counter to the latest challenge to the legacy of *Silent Spring* and the U.S. DDT ban shows that the ban did not prevent U.S. corporations from continuing to produce and distribute DDT to other countries and particularly to Africa, so the ban did not restrict the use of DDT in mosquito control campaigns to combat malaria. Instead, they suggest, as did Carson, that the evolution of resistance to DDT limited its efficacy, citing the case of Sri Lanka and its attempt to control malaria with DDT.[30] Nevertheless, by accepting the very narrow framework of this debate – namely, that the DDT ban in the U.S. significantly undercut efforts to control malaria-carrying mosquitos in Africa – Oreskes and Conway inadvertently contributed to the view that the U.S. ban on DDT solved the pesticide problem. In actuality, pesticides continued to present genuine risks to humans, wildlife, and ecosystems in the aftermath of the DDT ban.

By now, it should be clear that Rachel Carson viewed the pesticides problem as something much greater than just DDT, while recognizing that DDT, as the most widely used pesticide in America at the time, exemplified many of the problems of pesticides. In my recent book, *Banned: A History of Pesticides and the Science of Toxicology*, I examined the history of toxicology, which developed at least in part to assess the spectacular rise in newly derived chemicals during and after World War II, including pesticides. I acknowledged the important findings and arguments of such scholars as Oreskes and Conway, Rosner and Markowitz, and especially Daniel (for pesticide regulation). Despite these highly important and insightful works, I reached a different (and to me, surprising) conclusion: "As convincing as I find these case studies, my argument is simpler. When it came to organophosphates, no one seriously argued that they were safer than chlorinated hydrocarbons like DDT— and in that group, I include agricultural chemists, toxicologists, regulators, industry representatives and environmental advocates. In fact, as I have shown, in statement after statement, nearly everyone who testified in the various pesticide hearings following the publication of *Silent Spring* readily acknowledged that, with the exception of malathion, organophosphates posed greater risks to humans and wildlife."[31]

29 Oreskes N, Conway EM. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. New York: Bloomsbury Press, 2010: 216.

30 *Ibid*.: 236.

31 Davis FR. *Banned…*, *op. cit:*185.

Agricultural Insecticide Usage Trends

Top Insecticides 1966-2002
(1000 lbs AI/YR)

	1966		
1	Toxaphene	OC	34,605
2	DDT	OC	27,004
3	Aldrin	OC	14,761
4	Carbaryl	CB	12,392
5	Oil		11,419
6	Ethyl Parathion	OP	8,452
7	Methyl Parathion	OP	8,002
8	Diazinon	OP	5,605
9	Malathion	OP	5,218
10	TDE	OC	2,896
11	Methoxychlor	OC	2,578
12	Strobane	OC	2,016
13	Ethion	OP	2,007
14	Disulfoton	OP	1,952
15	Dicrotophos	OP	1,857
16	Heptachlor	OC	1,536
17	Azinphos Methyl	OP	1,474
18	Trichlorfon	OP	1,060
19	Endosulfan	OC	791
20	Endrin	OC	751
21	Dieldrin	OC	724
22	Lindane	OC	704
23	Chlordane	OC	526
24	Mexacarbate	CB	502
25	Phorate	OP	326
	Total Insecticide Use		**160,343**

1971		
Oil		73,950
Toxaphene	OC	37,464
Methyl Parathion	OP	27,563
Carbaryl	CB	17,838
DDT	OC	14,324
Ethyl Parathion	OP	9,481
Aldrin	OC	7,928
Phorate	OP	4,178
Disulfoton	OP	4,079
Bufencarb	CB	3,606
Malathion	OP	3,602
Diazinon	OP	3,167
Methoxychlor	OC	3,012
Carbofuran	CB	2,854
Azinphos Methyl	OP	2,654
Ethion	OP	2,326
Chlordane	OC	1,890
Endrin	OC	1,427
Heptachlor	OC	1,211
Methomyl	CB	1,077
Endosulfan	OC	882
Dicrotophos	OP	807
Lindane	OC	650
Trichlorfon	OP	617
Dieldrin	OC	332
TDE	OC	244
Strobane	OC	216
Total Insecticide Use		**243,720**

	1976		
1	Oil		60,000
2	Toxaphene	OC	34,178
3	Methyl Parathion	OP	23,350
4	Carbaryl	CB	15,829
5	Carbofuran	CB	11,623
6	Ethyl Parathion	OP	9,268
7	Phorate	OP	6,957
8	Disulfoton	OP	6,873
9	EPN	OP	6,249
10	Fonofos	OP	5,008
11	Methoxychlor	OC	4,057
12	Malathion	OP	3,936
13	Methomyl	CB	3,417
14	Azinphos Methyl	OP	2,644
15	Ethion	OP	2,639
16	Terbufos	OP	2,492
17	Diazinon	OP	2,470
18	Chlordane	OC	2,116
19	Monocrotophos	OP	1,917
20	Heptachlor	OC	1,667
21	Endosulfan	OC	1,653
22	Ethoprop	OP	1,148
23	Aldrin	OC	945
24	Trichlorfon	OP	932
25	Endrin	OC	866
26	Fensulfothion	OP	748
27	Acephate	OP	588
28	Dimethoate	OP	583
29	Phosmet	OP	523
30	Lindane	OC	370
	Total Insecticide Use		**232,852**

1982			
Oil		50,000	1
Carbofuran	CB	12,300	2
Methyl Parathion	OP	11,335	3
Carbaryl	CB	9,984	4
Terbufos	OP	8,632	5
Toxaphene	OC	6,596	6
Ethyl Parathion	OP	6,384	7
Fonofos	OP	5,486	8
Chlorpyrifos	OP	5,412	9
Phorate	OP	5,379	10
Methomyl	CB	4,253	11
Ethoprop	OP	2,907	12
Malathion	OP	2,521	13
Disulfoton	OP	2,443	14
Azinphos Methyl	OP	2,274	15
Aldicarb	CB	2,271	16
Diazinon	OP	2,114	17
Permethrin	SP	1,475	18
Dimethoate	OP	1,419	19
EPN	OP	1,373	20
Mevinphos	OP	1,277	21
Fenvalerate	SP	1,273	22
Ethion	OP	1,250	23
Acephate	OP	1,173	24
Endosulfan	OC	977	25
Methamidophos	OP	942	26
Phosmet	OP	903	27
Sulprofos	OP	794	28
Monocrotophos	OP	761	29
Naled	OP	745	30
Oxamyl	CB	667	31
			32
Total Insecticide Use		**173,157**	33
			34
			35
			36

OC=Organochlorine or Chlorinated Hydrocarbon	
OP=Organophosphate	
CB=Carbamate	
SP=Synthetic Pyrethroid	
Oil=Paraffinic Oil	
FL=Fluoridated insecticide	
A.I. = Active Ingredient	

1989		
Oil		35,000
Chlorpyrifos	OP	11,300
Terbufos	OP	10,246
Carbaryl	CB	8,616
Methyl Parathion	OP	7,652
Carbofuran	CB	7,156
Malathion	OP	6,327
Ethyl Parathion	OP	6,030
Phorate	OP	5,329
Aldicarb	CB	5,317
Dimethoate	OP	4,250
Fonofos	OP	3,220
Azinphos Methyl	OP	3,000
Acephate	OP	2,500
Ethoprop	OP	2,500
Methomyl	CB	2,345
Disulfoton	OP	2,023
Diazinon	OP	1,847
Ethion	OP	1,350
Methamidophos	OP	1,259
Endosulfan	OC	1,100
Fenvalerate	SP	1,000
Phosmet	OP	1,000
EPN	OP	975
Thiodicarb	CB	950
Profenofos	OP	777
Mevinphos	OP	757
Phosalone	OP	750
Methidathion	OP	600
Naled	OP	600
Trichlorfon	OP	568
Dicrotophos	OP	550
Monocrotophos	OP	550
Cypermethrin	SP	500
Esfenvalerate	SP	500
Permethrin	SP	450
Total Insecticide Use		**153,387**

1992		
Oil		51,102
Chlorpyrifos	OP	14,765
Terbufos	OP	8,690
Methyl Parathion	OP	5,962
Carbofuran	CB	5,101
Carbaryl	CB	4,543
Phorate	OP	4,453
Cryolite	FL	4,053
Aldicarb	CB	4,022
Propargite	OS	3,628
Acephate	OP	3,390
Malathion	OP	3,378
Fonofos	OP	3,234
Methomyl	OP	2,755
Dimethoate	OP	2,619
Azinphos-Methyl	OP	2,549
Ethyl Parathion	OP	2,318
Profenofos	OP	2,063
Disulfoton	OP	1,807
Endosulfan	OC	1,797
Thiodicarb	CB	1,706
Ethoprop	OP	1,450
Dicofol	OC	1,392
Diazinon	OP	1,266
Methamidophos	OP	1,088
Permethrin	SP	1,069
Ethion	OP	991
Oxamyl	OP	946
Phosmet	OP	941
Sulprofos	OP	852
Dicrotophos	OP	666
Fenamiphos	OP	615
Total Insecticide Use		**149,117**

	1997		
1	Oil		102,337
2	Chlorpyrifos	OP	13,464
3	Terbufos	OP	6,516
4	Methyl Parathion	OP	5,917
5	Malathion	OP	5,810
6	Carbaryl	CB	4,858
7	Aldicarb	CB	4,278
8	Carbofuran	CB	3,398
9	Phorate	OP	3,218
10	Cryolite	FL	2,560
11	Propargite	OS	2,539
12	Acephate	OP	2,462
13	Azinphos-Methyl	OP	2,091
14	Methomyl	OP	1,997
15	Dimethoate	OP	1,897
16	Endosulfan	OC	1,601
17	Phosmet	OP	1,333
18	Disulfoton	OP	1,196
19	Permethrin	SP	1,066
20	Ethoprop	OP	1,011
21	Methamidophos	OP	966
22	Oxamyl	OP	939
23	Diazinon	OP	918
24	Profenofos	OP	880
25	Thiodicarb	CB	821
26	Dicofol	OC	787
27	Fenamiphos	OP	727
28	Naled	OP	605
29	Tefluthrin		577
30	Ethyl Parathion	OP	529
31	Ethion	OP	505
32			
	Total Insecticide Use		**182,401**

2002			
Oil		91,606	1
Chlorpyrifos	OP	8,481	2
Malathion	OP	5,132	3
Aldicarb	CB	3,419	4
Terbufos	OP	3,363	5
Carbaryl	CB	2,986	6
Acephate	OP	2,525	7
Methyl Parathion	OP	2,148	8
Kaolin	MN	1,690	9
Phosmet	OP	1,495	10
Propargite	OS	1,407	11
Dimethoate	OP	1,346	12
Azinphos-Methyl	OP	1,224	13
Phorate	OP	1,197	14
Cryolite	FL	1,102	15
Carbofuran	CB	1,015	16
Dicrotophos	OP	980	17
Methomyl	OP	918	18
Endosulfan	OC	868	19
Diazinon	OP	858	20
Oxamyl	OP	748	21
Tefluthrin		630	22
Permethrin	SP	586	23
Tebupirimphos		538	24
Ethoprop	OP	434	25
Fipronil		419	26
Total Insecticide Use		**141,910**	

1966 - 1989 figures based on data in Leonard P. Gianessi, "U.S. Pesticide Use Trends: 1966-1989," Resources for the Future, 1992.
1992 - 2002 figures ased on data in Leonard P. Gianessi and Nathan Reigner, "Pesticide Use U.S. Crop Production: 2002," Croplife Foundation, 2006.

Fig. 2 Top Insecticides 1966-2002

But what happened on the ground? Where did farmers turn for insect control in the years following the DDT Ban? As Table #1 shows, despite the concerns regarding the toxicity of organophosphates, this was the class of pesticides to which farmers turned after the 1972 DDT Ban. As the EPA banned DDT then later aldrin, dieldrin and other chlorinated hydrocarbons, farmers shifted to organophosphates. In light of the high toxicities of most organophosphates, it is somewhat surprising that the aggregate application rates remained high. Other countries also banned DDT and chlorinated hydrocarbons and in the process adopted organophosphate insecticides. China, for example, banned DDT in 1983. Like in the U.S., Chinese farmers adopted other chlorinated hydrocarbons and organophosphates, most of which carried much greater toxicities than DDT. The problems associated with organophosphates extended beyond the very real risk to farmworkers and wildlife. Organophosphates have resulted in accidental poisoning, most recently in Bihar, India, where 22 children died after consuming a school lunch inadvertently contaminated with one of the pesticides.[32] Organophosphates also emerged as significant tools in self harm and suicides (Fig. 2).[33]

To say that the history of pesticides and toxicology is complex risks profound understatement. That said, the so-called controversy regarding DDT and malaria in Africa ignores a highly significant issue. Put simply, "If not DDT, then which pesticides?" To focus on DDT alone disregards greater challenges posed by pesticides. Oreskes and Conway made many important and decisive points against DDT, as supported in the literature from *Silent Spring* forward. Nevertheless, the debate itself, much like the evolution-creation debates, was deeply flawed. Reducing the problem of pesticides, an incredibly diverse collection of chemicals, to DDT alone brushes aside decades of research, analysis, legislation, regulation and, most importantly of all, usage patterns! It is of course a great irony that the highly toxic organophosphates replaced DDT and the chlorinated hydrocarbons. There is little doubt that the DDT ban contributed to the recovery of birds of prey such as bald eagles, osprey and peregrines in North America. But neither Rachel Carson nor her many sources (toxicologists, ecologists and physicians) supported replacing DDT and the chlorinated hydrocarbons with the highly toxic organophosphates.

Conclusion: Wicked Problems Redux: Neonicitinoid Insecticides

By way of conclusion, we should consider the pesticides that replaced the organophosphates in U.S. agriculture. Drawing on the research of Izuru Yamamoto at the Tokyo University of Agriculture, agricultural chemists working with support from Bayer and Shell successfully developed and patented several "neonicotinoids," also Yamamoto's term, during the 1980s and 1990s. As a class, neonicitinoid insecticides showed promise as systemic insecticides that would be absorbed by crops.[34] Once again, a fog of scientific uncertainty envelops the most widely used agricultural insecticides in the world. Neonicitinoids account for one quarter of insecticides used worldwide with an estimated value of 2.5 billion US dollars. The EPA has deemed neonicitinoid insecticides safe. Yet, more and more scientists worry that these chemicals are responsible for ecological disruption and the destruction of populations of birds, bees and aquatic organisms. Such risks have prompted action by the European Commission, which has restricted the use of neonicitinoids.[35]

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32 Harris G, Kumar H. Contaminated lunches kill 22 children in India. *The New York Times,* July 17, 2013. http://www.nytimes.com/2013/07/18/world/asia/children-die-from-tainted-lunches-at-indian-school.html Accessed on July 18, 2013. See also Subramanian M. Bihar school deaths highlight India's struggle with pesticides. *The New York Times*, July 30, 2013. http://india.blogs.nytimes.com/2013/07/30/bihar-school-deaths-highlight-indias-struggle-with-pesticides/ Accessed on August 20, 2013.

33 Hvistendahl M. In Rural Asia, Locking Up Poisons to Prevent Suicides. *Science*, 16 Aug 2013, 341: 738-9.

34 Yamamoto I. Nicotine to nicitinoids: 1962 to 1997. In Yamamoto I, Casida J. *Nicotinoid Insecticides and the Nicotinic Acetylcholine Receptor*. Tokyo: Springer-Verlag, 2008: 3-27.

35 Carrington D. EU agrees total ban on bee-harming pesticides. *The Guardian*, 27 April 2018.

It would be foolish to overdraw comparisons between the past and present and yet the similarities recall the discussion of risk, benefit and uncertainty. As regulators review neonicitinoids and the risks they pose to ecosystems and wildlife, we should look to *Silent Spring* and a century of pesticides and toxicology for models to evaluate novel risks. In fact, many of the neonicitinoids are systemic insecticides, and when applied as seed coatings, they are absorbed by the tissues of the plant: the stalks, leaves and flowers. Neonicitinoids have been involved in declines of honeybees and grassland birds.

The story of chemical insecticides has constituted a wicked problem from the time of their initial development and deployment in agriculture to the present (and will continue to do so in the future). While industrial agriculture remains wedded to insecticides, toxicologists have long noted the unintended associated consequences in the form of exposure for humans, wildlife, and ecosystems. Yet, when one class of insecticides undergoes scrutiny and regulation, chemical corporations introduce alternatives that have uncertain environmental risks. Rachel Carson drew attention to the problem of pesticides in 1962. Yet, more than fifty years later, pesticides and the wicked problems associated with their widespread use in agriculture around the world remain very much in effect.