TRAVELING TOXICS

The Science, Policy, and Management of Persistent Organic Pollutants

by Noelle Eckley

Just a little more than half a century ago, the development of new pesticides and industrial chemicals was widely hailed as a miracle of progress. Today, because of their adverse effects on the environment and human health, many of these chemicals have been banned or severely restricted by countries around the world. Chemicals like DDT (dichlorodiphenyltrichloroethane), which was once advertised as the "benefactor of all mankind," have become global pollutants. PCBs (polychlorinated biphenyls), originally used in electrical equipment, have shown up in fish in the Great Lakes and in the blubber of seals in the Arctic. After decades of extensive use and release, contamination from the class of chemicals termed "persistent organic pollutants" (POPs) now affects every corner of the Earth.

In the environment, these substances contaminate food supplies, cause toxic effects in wildlife, and pose risks to human health. POPs are organic chemicals characterized by their persistence in the environment, their tendency to accumulate in the food chain, and their ability to travel long distances in air and water, posing a risk to human health and the environment far from the site of their use or release. The most well-known POPs are the pesticide DDT, the industrial chemicals PCBs, and the industrial byproducts dioxins and the chemically similar furans.

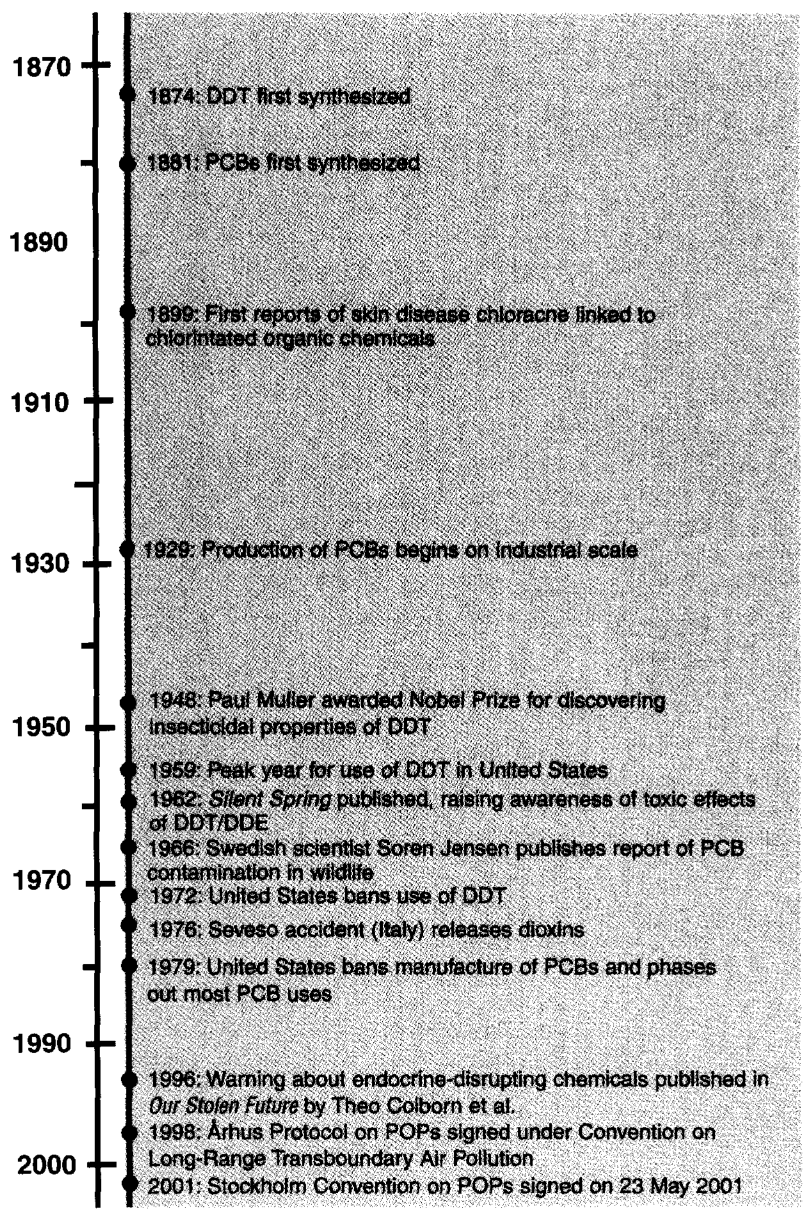
Addressing the problems caused by these substances is a complex challenge that requires both scientific information and political will. Defining a chemical as a POP involves not only looking at scientific data but also making policy judgments. Much controversy remains in assessing the potential impacts and risks from human and environmental exposure to POPs. Policies that deal with POPs involve more than simply banning production of certain commercial chemicals; they include, for example, finding pesticide substitutes, cleaning up contaminated sites or obsolete stockpiles, monitoring exposure and effects, and implementing cleaner technologies.

State of the Science

Widespread use of commercially produced POPs began in the mid-twentieth century. The impacts of their accumulation in the environment began to be apparent in the 1950s and 1960s (see Figure 1 on this page for a timeline on POPs). In 1962, Rachel Carson's classic book, *Silent Spring*, warned of the effects of pesticides on bird populations and raised awareness about the dangers of DDT and other pesticides to wildlife.[1] The DDT metabolite, DDE, was found to be responsible for eggshell thinning in several species of birds, including bald eagles and peregrine falcons. The early scientific warnings communicated in *Silent Spring* were confirmed by further research. For example, in Sweden, peregrine falcons were particularly affected by DDE: Their population declined from 350 pairs in the 1940s to fewer than 10 pairs in the 1970s.[2] (Since the peak of contamination in the 1970s, however, the concentrations of some POPs in the environment have declined, and some of these bird populations have recovered.) The toxic impacts of POPs include carcinogenic, reproductive, immune, and endocrine effects in humans and wildlife.

One particularly well-studied class of compounds that illustrates the range of toxic effects of POPs are the dioxins. Important sources of dioxins include waste incineration, the manufacture of chlorinated herbicides, and pulp and paper bleaching. Dioxins are a collection of chemicals that share a similar structure. The dioxins of concern are those with the most toxic effects—the polychlorinated

Figure 1. POPs Timeline, 1870–2001



SOURCE: N. Eckley.

dibenzo-p-dioxins, a set of 75 structurally similar compounds. The most toxic of these, and the most high-profile of the dioxins, is 2,3,7,8-tetrachlorodibenzo-p-dioxin, also called 2,3,7,8-TCDD or TCDD. Other chemicals, such as polychlorinated dibenzofurans and certain PCBs, have mechanisms of toxicity similar to TCDD.

TCDD was first identified in 1957 as an unintended byproduct in the production of chemical herbicides, though the acute effects of dioxins and other chlorinated substances—particularly the skin disease chloracne—were reported as early as 1899 during the production of chlorinated chemicals. In 1976, a chemical plant accident in Seveso, Italy, released dioxins into a surrounding area, causing acute health effects among the general population. Rigorous scientific follow-up of exposed individuals has shown additional, long-latency health effects such as increased occurrences of cancer in the years since the accident.[3] In 1978, DOW Chemical published a key study that established the carcinogenicity of dioxins in rats.[4] Today, the twenty- and thirty-year epidemiological studies that began in the 1970s and 1980s are now increasingly revealing carcinogenic and other effects of exposure to dioxins.[5] For more than 10 years, the U.S. Environmental Protection Agency (EPA) has been engaged in a virtually continuous effort to conduct a scientific assessment of dioxins and their effects on human health; the latest draft was released in September 2000. (The box on this page describes EPA's dioxin reassessment.)

A new concern has emerged with evidence that some POPs mimic hormones and thereby disrupt endocrine systems. In 1996, the book *Our Stolen Future* publicized the "endocrine disruptor" hypothesis and reviewed evidence that synthetic chemicals were acting like the hormone estrogen and causing reproductive and behavioral abnormalities in humans and wildlife. For example, alligators in Lake Apopka, Florida, contaminated with the pesticides DDT and dicofol have developed genital abnormalities and reproductive difficulties.[6] Laboratory tests have supported these linkages; however, the extent of these endocrine-disrupting effects in human populations is still uncertain. One study has linked increased consumption of PCB-contaminated fish by mothers in the Great Lakes area with impaired cognitive functioning in their subsequent offspring.[7] Endocrine disruption has also been linked to decreased sperm counts in human males worldwide; however, this remains a controversial area of research (see the box on endocrine disruptors on page 28).

The key characteristics of POPs (as opposed to other chemicals to which humans and the environment are exposed) are their persistence in the environment and their tendency to accumulate up the food chain. Ironically, some of these chemicals—persistent pesticides like DDT in particular—are useful precisely because they are so persistent. Estimates of the half-life of DDT in soil range from a minimum of 2 years to a maximum of 16 years.[8] Because POPs are so persistent, they can travel long distances in the environment and bioaccu-

The U.S. Environmental Protection Agency's Dioxin Reassessment

The U.S. Environmental Protection Agency (EPA) recently completed a latest draft of a major scientific assessment of dioxins. EPA regulates dioxins under many of its different regulatory programs, and the reassessment will be used to help develop an agencywide strategy for regulating dioxins.[1]

EPA's first assessment of the human health risks related to dioxins was published in 1985. In 1991, in response to new scientific evidence of the carcinogenicity of dioxins, their mechanisms of action, and their noncancer effects, EPA initiated a reassessment of the effects of dioxin exposure on human health.[2] A draft of this reassessment was released for public comment in 1994 and was reviewed by the Science Advisory Board (SAB). SAB instructed EPA to reevaluate the final two chapters of this report, which were criticized by industry for being too conservative in the evaluation of the risk associated with exposure to dioxins (reporting more of a cancer risk than the data warranted). After many more years of work on the issue and numerous delays, a new draft was released for public comment in June 2000, and a further-revised draft was issued in September 2000.[3] The latest draft characterizes 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) as a human carcinogen and increases EPA's 1994 human cancer risk estimate for dioxin exposure to the general population by tenfold—meaning that the risk to the general public of developing cancer due to exposure to dixoins is ten times greater than previously thought. The draft also summarizes significant noncancer risks of exposure to dioxins, such as reproductive or developmental effects. EPA's latest draft estimates that the general population's cancer risk from dioxins is between 1 in 100 and 1 in 1,000. EPA has set an "acceptable level" of risk for cancer at 1 in 1,000,000; the reassessment estimates risks to the public several orders of magnitude above that level. The draft has been reviewed by SAB, and the controversy surrounding the reassessment is ongoing. In particular, SAB has criticized the classification of dioxins as human carcinogens as well as EPA's quantitative estimate of cancer risk to the general population.

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1. U.S. Environmental Protection Agency (EPA), "Dioxin: EPA Cross-Media Dioxin Strategy," Office of research and Development, 12 June 2000.

2. J. Johnson, "Dioxin Risk: Are We Sure Yet?" *Environmental Science and Technology* 29, vol. 1 (1995): 24A–25A.

3. EPA, *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds* Part III: Integrated Summary and Risk Characterization for 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds, EPA/600/P-00/001Bg (Washington, D.C., September 2000).

mulate through food chains to levels that pose a risk far from the site of their use or release. POPs are lipophilic: They concentrate in the fat of organisms (such as fish, which concentrate POPs from the surrounding water). These organisms in turn are eaten by other organisms (such as larger fish or seals). In this manner, the larger animals accumulate higher levels of these chemicals. The levels of POPs found in organisms that are high on the food chain, such as seals or polar bears, are sometimes many thousands of times higher than the levels in the surrounding environment. This is expressed numerically as a bioconcentration factor or a bioaccumulation factor.[9]

POPs travel globally predominantly via the atmosphere; however, their behavior in the environment is quite complex. For some POPs, long-range movement through water or via migratory species can be an important mode of transport. Because POPs tend to partition into multiple environmental media, they can be present in air, soil, water, or living organisms. Because POPs are semi-volatile compounds, they can travel from lower to higher latitudes through a series of volatilizations and condensations—volatilizing in warmer climates, condensing in colder climates, and repeating the process with the seasonal cycles. This process, known as the "grasshopper effect," tends to move atmospheric POPs poleward. As data have shown, POPs accumulate in Arctic ecosystems.[10] Some atmospheric sources of POPs and their routes to the Arctic are illustrated in Figure 2 on page 29. High levels of POPs have been measured in the Arctic environment, as well as in Arctic animals and human populations. Research has shown that the concentrations of hexachlorocyclohexane in water from samples collected along the Pacific coast increase with latitude.[11] (Figure 3 on page 30 shows data on hexachlorocyclohexane concentrations along the Pacific coast.) Because indigenous people in the Arctic depend on a traditional diet composed of foods high in fat (where contaminants accumulate), POPs pose a particular risk to these communities.[12]

Compiling lists of well-known substances of concern based on scientific analyses of their persistence and bioaccumulation has been a major focus of regulating POPs. There are no definite thresholds of persistence or bioaccumulation that separate POPs from non-POPs. However, through a combination of scientific evidence and policy judgments, regulators have set certain criteria to

Endocrine Disruption

The contention that synthetic chemicals in the environment can cause numerous reproductive, developmental, immunological, and neurologic effects on humans and wildlife populations has been extremely controversial—that is, industry has questioned the science. The publication in 1996 of the book *Our Stolen Future* by Theo Colborn et al. publicized the "endocrine disruptor hypothesis" and presented scientific evidence showing linkages between chemicals and endocrine effects in the environment.[1] Since then, there has been much scientific assessment and policy awareness of these substances. The National Research Council (NRC) issued a report in 1999 after a four-year study on the state of science on what they termed "hormonally active agents."[2] The U.S. Environmental Protection Agency has set up a screening program to identify potential endocrine-disrupting substances; the European Parliament has recommended further assessment and policy action. Data on endocrine-disrupting effects are increasing, and the evidence is mounting that such chemicals can cause significant effects on wildlife as well as on human populations at levels typically observed in the environment.

Endocrine-disrupting substances can interfere with hormone systems by mimicking, blocking, or stimulating the natural hormones in the body. Some synthetic chemicals mimic the effects of the hormone estrogen. The synthetic estrogen diethylstilbestrol (DES), provides an example of the types of effects that these chemicals can produce. DES was given to pregnant women between 1940 and 1970 to prevent miscarriages and premature births; many years later, it was found to cause rare vaginal cancers in the daughters of women who had taken the drug during pregnancy. Laboratory tests of some hazardous chemicals, such as DDT and PCBs, have been shown to produce similar sorts of reproductive effects, and such effects have also been observed in wildlife and human populations. For example, the NRC report lists effects in fish populations exposed to effluents from sewage treatment plants, paper mills, and polluted waters of the Great Lakes. These effects include intersexes in trout exposed to sewage treatment plant effluent; increased egg and fry mortality in Great Lakes trout and salmon; thyroid enlargement in Great Lakes salmon; and, along Lake Superior, changes in plasma sex-steroid concentrations, decreased egg and gonad size, and delayed sexual maturity in white suckers exposed to effluents from paper mills. Research has also suggested that effects can depend on the timing of the dose. In other words, doses received at critical stages in development (especially prenatal development) can be particularly harmful. Some studies have shown declines over the last 50 years in men's sperm counts and have hypothesized that this decline is due to environmental chemicals. This continues to be an area of much scientific controversy.[3]

Though most POPs are known or suspected endocrine disruptors, not all endocrine-disrupting chemicals are POPs. Some other substances that have been linked to endocrine-disrupting effects are less-persistent pesticides, chemicals found in plastics (such as phthalates), and some heavy metals.

1. T. Colborn, D. Dumanoski, and J. P. Myers, *Our Stolen Future* (New York: Dutton, 1996).
2. U.S. National Research Council, *Hormonally Active Agents in the Environment* (Washington, D.C.: National Academy Press, 1999).
3. For more information on endocrine disruptors and their associated effects, see S. Krimsky, "Hormone Disruptors: A Clue to Understanding the Environmental Causes of Disease," *Environment*, June 2001, 22–31.

facilitate the identification of these problematic chemicals.[13] (Table 1 on page 30 compares the persistance and bioccumulation values of three international regulatory agreements on POPs.) Of the various lists of POPs of concern, the most high-profile one is the list of 12 POPs (the "dirty dozen") addressed by the United Nations Environment Programme (UNEP) under a global agreement, which covers 9 pesticides (including DDT), dioxins and furans, and PCBs. Table 2 on page 31 presents the UNEP list and a summary of the major uses and sources of these chemicals.

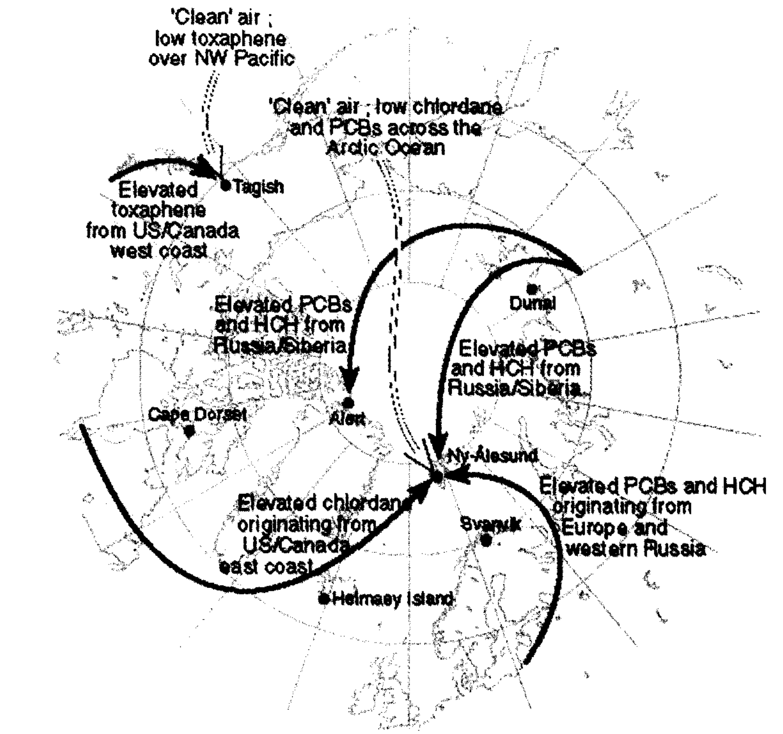
The pesticides included under the agreement have been used in a wide variety of applications. For example, DDT was used on agricultural crops, especially cotton, and continues to be used to control malarial-carrying mosquitoes in numerous countries. Heptachlor was used primarily against soil insects and termites. Mirex was used against fire ants in the southeastern United States. PCBs had a wide variety of industrial uses. Their dielectric properties made them useful in transformers and large capacitors as well as in other common products. Dioxins and furans are produced during the manufacture of other chemicals, the incineration of waste, and from numerous other industrial sources.

Policy Challenges

Though many of the uses and sources of chemicals have been banned or regulated by a large number of countries, POPs still pose significant challenges to regulators and policy makers. Although they are a global problem, they pose particular challenges in very local situations.

The endusers of intentionally produced POPs include small-scale farmers looking to control insects or weeds, electric power companies using PCBs in their transformers, and health ministries using pesticides for disease vector control. POPs are ubiquitous not only in the environment but also in everyday products. Wooden houses in some countries have been treated with heptachlor as a termiticide. Mirex was a constituent in some fire-retardant clothing. PCBs are present in electrical equipment manufactured prior to the 1970s. Modern society has used and continues to use POPs extensively, and the challenge for policy makers is not only to "turn off the tap" of production but also to deal with the risks posed by chemicals that have already been produced and dispersed.

Figure 2. POP sources and their routes to the Arctic

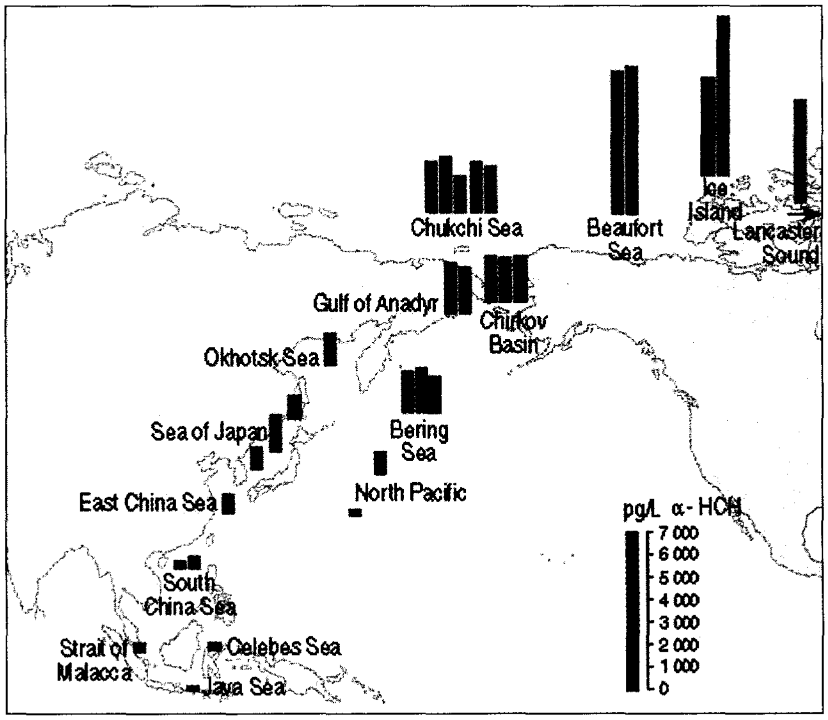


SOURCE: Arctic Monitoring and Assessment Programme, *AMAP Assessment Report: Arctic Pollution Issues*, Figure 6.6 (Oslo: AMAP, 1998).

One of the most high-profile continuing applications of a POP chemical is the use of DDT in malaria-control efforts in the developing world. Every year, more than one million people die from malaria, and 90 percent of these deaths occur in Africa. In approximately 22 developing countries, DDT is still used to control the mosquitoes that spread the disease. Though alternative pesticides and control measures exist, these countries continue to use DDT because it is effective and more affordable than the alternatives. To reduce the amount of DDT released into the environment, the World Health Organization (WHO) approves its use to control malaria only in indoor applications. International efforts have emerged to assist countries with financial and technical support to reduce or eliminate reliance on DDT for malaria vector control; however, the scale of the problem and the cost of providing assistance make this a significant challenge. WHO has begun to implement an action plan and a long-term strategy to reduce dependence on DDT for vector control.[14]

Once a POP chemical is banned or restricted, existing stockpiles of the chemicals must be disposed of. In some locations, there are significant stockpiles of obsolete chemicals that have deteriorated (for example, storage containers may be rotting or corroding, drums may be leaking or tipped over, or the chemical may no longer be fit for use) and pose environmental threats. This is a significant problem, especially in developing countries. The United Nations Food and Agriculture Organization (FAO) estimates that there are more than 100,000 metric tons of obsolete pesticide stocks

Figure 3. Hexachlorocyclohexane concentrations in surface waters along a meridional gradient



NOTE: The data presented here illustrate that concentrations of hexachlorocyclohexane increase with latitude, providing evidence that POPs migrate poleward; pg/L = picograms (10^{-12} grams) per liter; HCH = hexachlorocyclohexane.

SOURCE: Arctic Monitoring and Assessment Programme, *AMAP Assessment Report: Arctic Pollution Issues,* Figure 6.21 (Oslo: AMAP, 1998).

in developing countries, including large quantities of POPs such as dieldrin, hexachlorocyclohexane, and DDT. Between 15,000 and 20,000 tons of obsolete chemicals are estimated to be in Africa. Obsolete stocks are also a problem in parts of Asia and Eastern Europe. FAO's Collaborative Programme on Disposal of Obsolete Pesticides has taken steps to identify these pesticides—including a survey of 42 countries in Africa and the Middle East—and has initiated pilot projects to assist countries in cleanup efforts. Environmentally sound disposal of these POPs requires that they be incinerated in high-temperature hazardous-waste furnaces, which do not exist in developing countries. The combined cost of transport and destruction of obsolete pesticides is quite high: FAO estimates about $3,000–$4,500 per ton. In addition, sites around the stockpile have often been contaminated due to pesticide leakage. FAO estimates that approximately $500 million is needed to handle the problem of obsolete stocks. Awareness of this issue is increasing, however, and funding and technical assistance from developed countries has

Table 1. Criteria for selecting persistent organic pollutants

Criterion	United Nations Environment Programme, 2001	Convention on Long-Range Transboundary Air Pollution, 1998	North American Agreement on Environmental Cooperation, 1997
Log Kow[a]	5	5	5
Bioaccumulation Factor[b]	5,000	5,000	5,000
Persistence			
Air	2 days	2 days	2 days
Water	2 months	2 months	6 months
Soil	6 months	6 months	6 months
Sediment	6 months	6 months	12 months

[a]The Log Kow, the octanol-water partition coefficient, is a measure of a chemical's lipophilicity—the degree to which it tends to dissolve in octanol (a proxy for lipid) versus water.

[b]The bioaccumulation factor is a numerical representation of a chemical's tendancy to accumulate in living tissue and takes into account both environmental and dietary sources.

SOURCES: United Nations Environment Programme (UNEP), Stockholm Convention on Persistent Organic Pollutants, May 2001; United Nations Economic Commission for Europe (UNECE), Executive Body Decision 1998/2 on Information to be Submitted and the Procedure for Adding Substances to Annexes I, II, or III to the Protocol on Persistent Organic Pollutants, Århus, Denmark, ECE/EB.AIR/60, June 1998; and North American Agreement on Environmental Cooperation—Commission for Environmental Cooperation (NAAEC-CEC), Process for Identifying Candidate Substances for Regional Action under the Sound Management of Chemicals Initiative, Report to the North American Working Group on the Sound Management of Chemicals by the Task Force on Criteria (CEC, Montreal, Draft, July 1997).

Table 2. The uses/sources of the twelve substances regulated by the Stockholm Convention (2001)

Chemical	Use or source
Aldrin	Pesticide used to control soil insects such as termites, corn rootworm, wireworms, rice water weevil, and grasshoppers; to protect crops such as corn and potatoes; and to protect wooden structures from termites.
Chlordane	Insecticide used on agricultural crops including vegetables, small grains, maize, other oilseeds, potatoes, sugarcane, sugar beets, fruits, nuts, cotton, and jute. Also used to control termites.
DDT	Used on a variety of agricultural crops (esp. cotton) and for the control of disease vectors. Still used to control mosquito vectors of malaria in numerous countries.
Dieldrin	Used in agriculture to control soil insects and to control several insect vectors of disease, termites, wood borers, and textile pests.
Polychlorinated dibenzo-para-dioxins (dioxins)	Byproducts resulting from the production of other chemicals. Detected in emissions from the incineration of hospital waste, municipal waste, and hazardous waste; in emissions from the burning of coal, peat, and wood; and in automobile exhaust.
Polychlorinated dibenzofurans (furans)	Byproducts resulting from the production of other chemicals (similar to dioxins). Detected in emissions from the incineration of hospital waste, municipal waste, and hazardous waste; in emissions from the burning of coal, peat, and wood; and in automobile exhaust.
Endrin	Insecticide used on field crops (e.g., cotton and grains); and a rodenticide used to control mice and voles.
Hexachlorobenzene (HCB)	Fungicide for seed treatment, esp. for control of bunt of wheat. Also a byproduct of the manufacture of industrial chemicals, including carbon tetrachloride, perchlorethylene, trichloroethylene, and pentachlorbenzene.
Heptachlor	Insecticide used primarily against soil insects and termites; also used against cotton insects, grasshoppers, some crop pests, and to combat malaria.
Mirex	Insecticide used mainly against fire ants in the southeastern United States; also used to combat leaf cutters in South America, harvester termites in South Africa, western harvester ants in the U.S., and mealybug of pineapple in Hawaii. Also used as a fire retardant in plastics, rubber, paint, paper, and electrical goods.
Polychlorinated biphenyls (PCBs)	Mixtures of chlorinated hydrocarbons with a variety of industrial uses, including as dielectrics in transformers and large capacitors, as heat exchange fluids, as paint additives, in carbonless copy paper, and in plastics.
Toxaphene	Insecticide used primarily on cotton, cereal grains, fruits, nuts, and vegetables. Also used to control ticks and mites in livestock.

SOURCE: United Nations Environment Programme (UNEP), Decision 18/32: Persistent Organic Pollutants (UNEP Governing Council, 25 May 1995); and L. Ritter, K. R. Solomon, J. Forget, M. Stemeroff, and C. O'Leary, *An Assessment Report on: DDT-Aldrin-Dieldrin-Endrin-Chlordane-Heptachlor-Hexachlorobenzene-Mirex-Toxaphene-Polychlorinated Biphenyls-Dioxins, and Furans*, International Programme on Chemical Safety (IPCS), Inter-Organization Programme for the Sound Management of Chemicals (IOMC), December 1995.

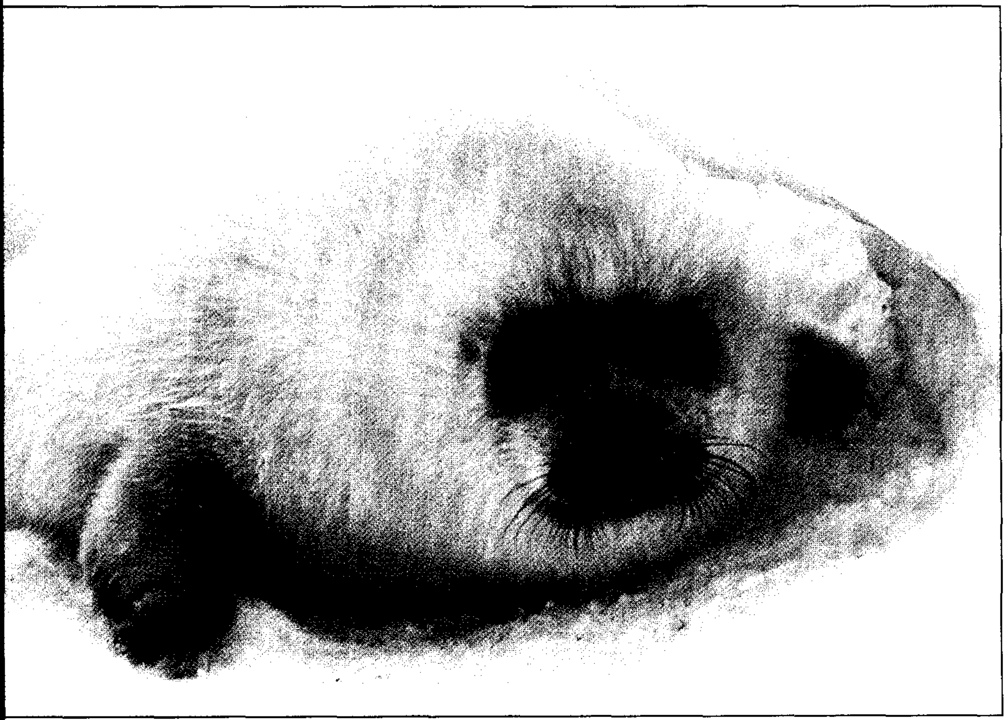
helped a number of developing countries to clean up contaminated sites.[15]

Another category of POPs—PCBs—requires extensive identification and disposal efforts. Because PCBs have been so widely used, it can be difficult to identify exactly where they are still present. Production of PCBs on an industrial scale began in 1929, and widespread use came shortly thereafter. For example, transformers in electrical equipment that dates from the mid-1970s, which may still be in use, often contain PCBs. Creating inventories of the locations and quantities of PCB-containing equipment in use is a first step toward addressing the problem. Many regulatory authorities (such as those in the United States, Canada, and Germany) consider articles to be "PCB-containing" if their PCB content is greater than 50 parts per million (50 mg/kg).[16] Equipment that contains PCBs must be disposed of in ways that will prevent their release into the environment.

Those POPs that are not intentionally produced pose an entirely different set of challenges. Many countries do not even know the amount of these chemicals that their industrial activities produce. Inventories of dioxin and furan emissions, for example, are extremely uncertain, even in countries where substantial quantification efforts have been undertaken. Many countries have not attempted to inventory POPs at all. In addition, present knowledge about dioxins and furans and their sources is based on the experiences of a few industrialized countries in the northern hemisphere.[17] The sources of dioxins that are the most significant in industrialized countries may not be the most significant sources in developing countries. For example, recent research has shown that open burning of household waste may be a significant source of dioxin and furan emissions.[18] (Whereas municipal waste incineration is common in industrialized countries, open burning may be a much more significant source of dioxins in developing countries, where it is commonly practiced.) International efforts to regulate these chemicals will help countries to develop inventories and action plans to reduce emissions.

In the 1960s, the thinning of the eggshells of several bird species, including peregrine falcons, was linked to the use of DDT. Since then, the DDT levels in the environment have fallen and some affected bird populations have recovered.

Have the policy actions on POPs to date actually made a difference in the state of the environment? Are Arctic ecosystems, for example, becoming less contaminated? Since the peak of contamination in the 1970s, the levels of PCBs and DDT in the environment in many areas have decreased—for example, in wildlife of the Baltic region. Less is known about the levels and trends of other chemicals. Research is ongoing in this area. Monitoring programs can also serve to identify other chemicals that are accumulating in the environment. For example, scientific evidence that brominated flame retardants were accumulating in the marine environment of northern Europe raised concerns about these chemicals.[19] The Arctic Monitoring and Assessment Programme was one of the more significant efforts to collect, analyze, and present monitoring information on POPs; the global POPs convention will also establish a monitoring and evaluation network to measure its effectiveness in reducing the levels of POPs in the biosphere.



PCBs have been detected in the blubber of Arctic seals, which, when consumed, poses a risk to human health. The high concentrations of POPs detected in Arctic animals provides evidence that these chemicals migrate poleward.

Cooperative Actions

POPs pose significant local problems, but their ability to travel long distances across national boundaries makes international cooperation necessary. The most recent and substantive effort to date has been the negotiation of a global convention on POPs under the auspices of the United Nations Environment Programme (UNEP). The convention was signed in Stockholm on 23 May 2001.

International action to address POPs began with their regulation under regional agreements. In the early 1990s, the Helsinki Commission (HELCOM), which focuses on the Baltic marine environment, addressed the problem of some POPs in the Baltic.[20] Hazardous substances, including some POPs, had been covered by agreements on preventing marine pollution, such as the Oslo and the Paris Conventions, which dealt with the northeast Atlantic region and came into force in 1974 and 1978, respectively.[21] As part of their efforts at cooperation on improving the environment of the Great Lakes, in 1997 the United States and Canada targeted a list of priority toxic substances for "virtual elimination" under a binational strategy. (A comparison of the chemical substances addressed under these different agreements is presented in Table 3 on this page.)

In the late 1980s, an assessment of POPs began under the auspices of the Convention on Long-Range Transboundary Air Pollution (LRTAP), a regional agreement under the United Nations Economic Commission for Europe. Parties to the LRTAP Convention include European Union countries, eastern European countries, the United States, Canada, and Russia. The issue of POPs was added to LRTAP's agenda by Canada when increasing scientific evidence emerged that its northern indigenous populations were affected by POPs from distant sources.[22] A scientific task force on POPs, set up under the LRTAP Convention to assess the environmental problems caused by POPs, recommended further action under the LRTAP Convention.[23] Further assessments examined lists of substances covered by previous regulation (for example, the Helsinki Commission and the Paris Commission) and prioritized a list of substances based on the criteria of persistence and bioaccumulation.[24] In January 1997, formal negotiations began under the LRTAP framework; the resulting protocol, which restricted the production of 13 commercially produced POPs and 3 byproducts, was signed in Århus, Denmark, in June 1998.

While LRTAP assessment and negotiations were in progress, UNEP initiated global action on a similar group of substances. International activities in the chemical management arena had been encouraged at the 1992 Rio Conference on Environment and Development.[25] At its Governing Council meeting in May 1995, UNEP initiated a global assessment process on 12 POPs.[26] Negotiations for a global agreement on POPs began in June 1998 and resulted in the signing of the Stockholm Convention in May 2001.

The Stockholm Convention includes several specific measures to regulate 12 POPs. It commits parties to prohibit or take measures necessary to eliminate the production, use, import, and export of nine commercially produced chemicals; to restrict the production and use of DDT to registered uses for vector control; and to develop action plans to minimize releases from unintentional POP production, with a phased-in requirement to use best available techniques to prevent releases from new sources.[27]

Specific provisions in the convention address PCBs and DDT in particular. Under the Stockholm Convention, the production of PCBs is prohibited. Parties must make "determined efforts" to identify, label, and remove certain types of PCB equipment in use (for example,

Table 3. Selected persistent toxic substances and their regulation and prioritization under different international agreements

Chemical	UNEP	LRTAP	HELCOM	Great Lakes	OSPAR
Aldrin	√	√	√	√	
Chlordane	√	√	√	√	
DDT	√	√	√	√	
Dieldrin	√	√	√	√	
Endrin	√	√	√		
Heptachlor	√	√	√		
Hexachlorobenzene	√	√	√		
Mirex	√	√		√	
Toxaphene	√	√	√	√	
Polychlorinated dibenzo-p-dioxins (PCDDs)	√	√		√	√
Polychlorinated dibenzofurans (PCDFs)	√	√		√	√
Polychlorinated biphenyls (PCBs)	√	√	√	√	√
Chlordecone		√	√		
Hexachlorocyclohexane (HCH)		√		√	
Hexabromobiphenyl		√			
Polycyclic aromatic hydrocarbons (PAHs)		√	√	√*	
Pentachlorophenol (PCP)				√	√
Organic tin compounds				√	√

*Benzo(a)pyrene only

SOURCE: Stockholm Convention, 2001 (UNEP); Århus Protocol, 1998 (LRTAP); Helsinki Convention (HELCOM), 1992, listed substances; Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes, 1997, Level I Substances; and OSPAR 1998 List of Priority Substances.

transformers and capacitors) by 2025. For DDT, the convention establishes a "DDT register" for those parties who wish to continue using DDT for disease vector control in accordance with WHO recommendations and guidelines where alternatives are not available or affordable. Those parties must report on these uses and then develop action plans with the goal of reducing and ultimately eliminating the use of DDT. In addition to these specific provisions, the convention also addresses stockpiles and wastes, information exchange, research and development, and monitoring activities.

During the negotiation of the Stockholm Convention, significant controversy arose over the provisions that incorporated precaution into the convention, the disposal of stockpiles and wastes, and restrictions on trade. Precaution was a significant area of disagreement between the European Union—favoring explicit reference to the "precautionary principle"—and the United States—advocating a precautionary approach with decisionmaking based on the assessments of scientific working groups. The convention limits trade in POPs by only allowing trade for permitted chemical uses or environmentally sound disposal. The negotiations sought to balance the requirements of this convention with free trade agreements. A degree of flexibility is built into the convention; that is, parties are permitted to use their existing regulatory schemes to deal with POPs. For example, a provision restricting the production of new chemicals with POP properties will be implemented within the parties' existing regulatory and assessment schemes for new chemicals.

A major component of the Stockholm Convention is the commitment from developed countries to provide technical and financial assistance to developing countries and countries with economies in transition for the implementation of the convention's requirements. The Global Environment Facility (GEF)—an international cooperative funding mechanism that was set up to address the issues of biodiversity loss, climate change, degradation of international waters, and ozone depletion—will coordinate this financial mechanism until the Conference of the Parties to the Convention decides on permanent arrangements.

Though the Stockholm Convention addresses only 12 substances, it does allow additional POPs to be added to the agreement at a later date. Candidate substances may be proposed by a party and will be evaluated with respect to persistence and bioaccumulation criteria thresholds (see Table 1) and consideration of their toxicity based on a risk profile. A procedure for this evaluation of additional chemicals is detailed in an annex to the convention. Some substances that have been suggested as early additions to the list include the additional chemicals addressed under the LRTAP POPs protocol.[28]

Dioxins are byproducts of the pulp and paper bleaching process. By developing alternative industrial processes and using best available technologies to minimize releases, the environmental levels of unintentionally produced POPs could be reduced.

The convention's provision on the addition of substances to the list of POPs—as well as the provision on preventing the introduction into the environment of new substances that meet the criteria for classification as POPs—is designed to be precautionary in nature.

Conclusions

The historical and widespread use of persistent organic chemicals in the mid-twentieth century continues to impact today's environment. Though many of these chemicals have already been banned in a majority of countries around the world, international action to address POPs does not merely codify the status quo; in some areas of concern it goes beyond what countries have already done. For example, significant work will proceed under the Stockholm Convention on issues such as DDT and vector control, stockpiles and wastes, and PCB cleanup. Further, the Stockholm Convention addresses the issue of chemical byproducts such as dioxins, which are likely to pose a growing threat as developing countries increase their industrial production and which to date have not received the attention that PCBs and pesticides have.

The biggest upcoming policy challenge is the ratification and implementation of the Stockholm Convention. The convention will enter into force only after 50 countries ratify it. (The extremely ambitious goal expressed at the signing was that the convention would be ratified by the time Rio+10 convenes in 2002.) GEF is currently engaged in a regionally based assessment of persistent toxic substances that links strongly with the activities of the convention. Other international activities on chemicals are ongoing, and some of these agreements and activities address similar substances. For example, the 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and

Many of the large stockpiles of obsolete POPs are deteriorating and pose environmental threats worldwide. This problem is especially acute in the developing world, where facilities for sound environmental disposal do not exist and funds for transport are lacking.

Pesticides in International Trade made legally binding an existing voluntary procedure requiring explicit notification and approval ("prior informed consent") before extremely hazardous chemicals can be imported into a country. There have been discussions about the possibility of addressing toxic heavy metals under a further international agreement, and UNEP has just begun an assessment of the sources and effects of mercury contamination around the world.

To advance the science of POPs, more data about these chemicals and their presence in the environment will be needed. Identifying additional POPs and collecting data on their properties requires further action, as does monitoring the concentrations of chemicals in the environment to determine the effectiveness of policy actions. In addition, further work analyzing the extent to which human populations are affected by background levels of endocrine-disrupting substances and testing substances for their endocrine-disrupting properties continues and should continue to influence policies in this area. Finally, the effects of multiple chemical exposures have yet to be identified and assessed.

Though POPs are but a small subset of hazardous chemicals that pose a risk to human health and the environment, they are the most well known; therefore, scientific research efforts and policy actions have focused on these chemicals—in particular the "dirty dozen." Because of their propensity to travel through the air and water across national boundaries, POPs require international action; no single government can fully address the problem.

For the vast majority of chemicals on the market today, little or no toxicity data are publicly available. In 1999, an analysis by the European Chemicals Bureau estimated that 86 percent of chemicals deemed "high production volume chemicals"—those with production volumes exceeding 1,000 tons per year—did not have a sufficient "base set" of minimum toxicity data results. Of these, 21 percent had no data available at all.[29] In the United States, 93 percent of such chemicals have insufficient test data, and 43 percent have no data available at all.[30] In response to concerns about nonassessed chemicals, there have been a number of proposals to change the way chemicals are regulated. For example, it has been suggested that all chemicals should be required to have a base set of toxicity data before marketing or that all persistent and bioaccumulative chemicals should be phased out.[31] Recent efforts, especially in the United States, have focused on voluntary cooperations with the chemical industry to provide data and information on high production volume chemicals; industry initiatives have also emphasized product stewardship and responsible management.[32]

Policy on chemicals, in general, is at a crossroads. On one hand, efforts to identify and deal with the problem chemicals of the past—POPs—continue to move forward. On the other hand, controversy surrounds the formulation of policies to identify, assess, and regulate those chemicals that might pose risks in the future; that is, policies on additional chemicals will be more controversial because fewer countries have yet to ban or restrict them. Discussions of policy issues surrounding chemicals often focus on the "precautionary principle"—the idea that lack of scientific certainty should not be used to delay prudent policy action to mitigate potential environmental risks.[33] While international efforts continue to deal with the problems of the past, one of the central challenges facing scientists and regulators is preventing the environmental problems of the future.

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21. The OSPAR Convention, which was signed in 1992, has since merged and replaced the Oslo and Paris Conventions. Fifteen countries are parties to the OSPAR Convention: Belgium, France, Iceland, Luxembourg, Norway, Spain, Switzerland, Denmark, Finland, Germany, Ireland, the Netherlands, Portugal, Sweden, and the United Kingdom. The European Union is also a party. See http://www.ospar.org.

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26. UNEP's list of 12 POPs was taken from an intermediate working draft of the LRTAP assessment process. The LRTAP process later added four additional chemicals; UNEP's list remains unchanged.

27. The concept of "best available techniques" is used in several national and international regulatory schemes. It requires that the controls, technologies, and practices used be the most effective available to protect the environment, taking into account economic and technical viability. What is considered "available," therefore, may be different in different national contexts.

28. These are the pesticides chlordecone and hexachlorocyclohexane (HCH, including lindane, the γ-isomer); the industrial chemical hexabromobiphenyl; and the byproducts polycyclic aromatic hydrocarbons (PAHs).

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33. A forthcoming publication of interest in this area is European Environment Agency, *Late Lessons from Early Warnings: The Precautionary Principle 1898–1998* (Copenhagen: forthcoming, 2001). The report will include a chapter on PCBs.