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DDT and PCB in the Atlantic

George R. Harvey

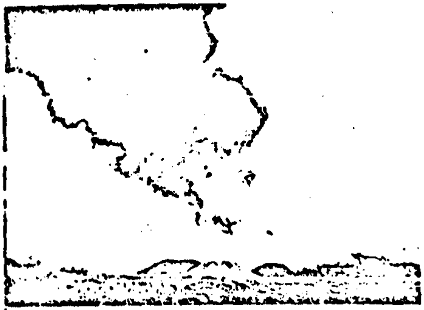
The insecticide DDT was introduced to world agriculture and public health after World War II. It was valued for both its toxicity to insects and its persistence in the field. It is estimated that over ten million tons have been used during the last thirty years. Polychlorinated biphenyls (PCB) were first introduced to the electrical industry in 1935 as dielectric and insulating fluids. Because of their low conductivity, heat stability, resistance to bacterial degradation, and solvent properties they soon found their way into hundreds of commercial products. About one million tons have been manufactured to date. It was inevitable that the same properties that make these chemicals so valuable in commerce, agriculture, and health would lead to their accumulation and persistence in the environment. Also, since the oceans cover most of the surface of the globe, it would have been reasonable to predict that large fractions of these chemicals would find their way to the sea. These predictions would have been of little concern if both DDT and PCB were not members of a class of organic compounds known as chlorinated hydrocarbons, substances that are physiologically active in a deleterious way. They are not lethal, as are the nerve gases, but they insidiously interfere with important biochemical processes, leading to a variety of unnatural symptoms.

The accumulation of chlorinated hydrocarbons in the marine environment has lead to reproductive failures in populations of sea birds, such as the Anacapa Island brown pelican. (Franklin Gress)

Public awareness of the possible effects of chlorinated hydrocarbons on the environment was first roused by Rachel Carson in her now famous book *Silent Spring*, published in 1962. Although the book contained many errors, it struck a sensitive international nerve and catalyzed the formation of federal pollution agencies and new areas of research funding, and heightened public awareness of the classical science of ecology. Still, by 1970 there was no information available on the presence, if any, of DDT or PCB in the open sea.

Being uniquely situated at an oceanographic laboratory with open-sea capabilities, we began to study the distribution of chlorinated hydrocarbons in the sea by making a diverse collection of fish and crustacea on a cruise that transected the North Atlantic between the Cape Verde Islands and Woods Hole during November and December of 1970. Since that time we have made a dozen cruises into the open Atlantic to collect and analyze organisms, water, air, and sediments as a part of the Environmental Quality Program of the International Decade of Ocean Exploration (IDOE), an office of the National Science Foundation.

When our work began in 1970, we proceeded on the following assumptions: We would find mainly DDT and its derivatives



PCB released during the burning of municipal dumps may reach coastal waters via atmospheric transport and fallout. (Massachusetts Audubon Society)

and little, if any, PCB; we would note decreasing concentrations of DDT in fish and water as we moved seaward; we would observe food chain magnification of chlorinated hydrocarbons in marine animals; and we would detect toxic effects of DDT and PCB. Fortunately, our approaches were flexible because all four assumptions were wrong.

More than ten times as much DDT as PCB had been used during previous decades. All the DDT had been sprayed directly into the environment, while the PCB had to have leaked or been accidentally introduced. Yet, our first few analyses of Atlantic organisms collected in 1970 revealed ten to one hundred times more PCB than DDT. These initial observations did not change during our subsequent work and eventually led to the conclusion that DDT is not as persistent as once believed and is confined fairly closely to the point of its introduction. Recent work at the Gulf Breeze (Florida) Laboratory of the U.S. Environmental Protection Agency (EPA) has shown that the half-life of DDT in naturally illuminated seawater is about ten days. Consequently, DDT is now undetectable in Atlantic deep-sea water or sediments, while PCB has been measured in sediments lying under 5500 meters (18,000 feet) of water. Along the coast of the United States, DDT is more abundant and can be detected in sediments, shellfish, and finfish.

After examining a large body of data on the PCB and DDT content of seawater, plankton, and fish, we faced a second unexpected conclusion: there was no trend toward a decrease in the chlorinated hydrocarbon content of the water or the plankton as one went seaward. This is illustrated in Figure 1. Looking for an explanation, we measured the PCB and DDT content of the air over the Atlantic and the

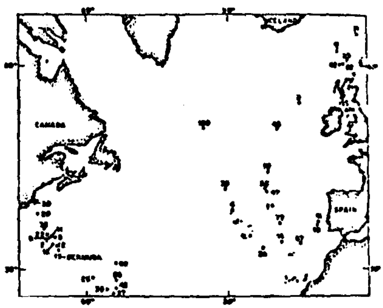


FIGURE 1. PCB concentrations (in parts per trillion) in the surface waters of the North Atlantic in 1972.

sediments beneath the water at several sites from inshore to the open sea. There we did find a very rapid decrease in concentrations away from the coast. This is illustrated for the atmospheric concentrations in Figure 2. The question we encountered was, if more PCB and DDT are getting into the coastal ocean than into the open sea, why aren't concentrations higher in coastal waters, plankton, and fish? We now believe that the greater amounts of solid particles in the coastal waters can adsorb PCB and DDT from the water while falling to the sediments. In fact, we have demonstrated in the laboratory that ocean particles—a mixture of clay, dead

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plankton, algae skeletons, and so on—can adsorb one million times more PCB than an equal quantity of water can dissolve. In the open ocean, where there is very little particulate matter, the adsorption process is slower. Thus, the near-shore ocean, which is the source of most of our fish, has been protected from having higher and probably toxic concentrations of chlorinated hydrocarbons in the water by virtue of having a higher load of solid particles. The blue water of the open ocean, because of its low particle population, would be ineffective in protecting the coastal zone. Fortunately,

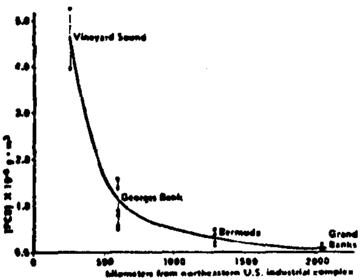

FIGURE 2. PCB concentrations in atmosphere directly over the western North Atlantic in spring 1973.

much less PCB or DDT ever reaches the open ocean.

Another unexpected result of our data and that of others was a lack of support for the concept of food chain magnification, as first popularized by Rachel Carson. Although, like others, we found some carnivorous fish with more chlorinated hydrocarbons than herbivorous fish, or large fish with a higher body burden of DDT than small fish, we also found the reverse in many cases. For example, plankton, although they are at the base of the food chain, contain the highest PCB concentrations of any organisms in the sea analyzed to date (about 200 micrograms per kilogram). In contrast, barracuda contain about 10 micrograms per kilogram, and flying fish, which feed on plankton, contain one hundred times less PCB or DDT than plankton. Conversely, sharks, which, like barracuda, feed on anything that moves, contain PCB and DDT levels almost as high as those in plankton. In fact, there are now sufficient data from many sources in the scientific literature to conclude that food chain magnification of pollutants is not a useful concept with water-breathing animals. However, air-breathing animals such as seals, sea lions, and sea birds do seem to concentrate DDT and PCB from their diets and to build up enormous quantities in their fat stores. For example, open-ocean-feeding sea birds, such as the great skua and the British storm petrol, can accumulate as much as 20 parts per million PCB from their diets. The reasons for the lack of food chain magnification among gilled organisms are unknown but probably relate to differences in body chemistry rather than trophic level. Differences in PCB concentrations in various water- and air-breathing animals are illustrated in Table 1.

During our cruises we have not observed any effects attributable to DDT or PCB. Planktonic distribution and the size of most

Table 1

PCB Concentrations in Various Reservoirs of the Atlantic Ocean

Reservoir	Concentrations (parts per billion)
Sea mammals	3000
Sea birds	1200
Mixed plankton	200
Finfish of upper ocean	50
Fish of mid-water depths	10
Bottom-living invertebrates	1
Deep-sea sediments	1
Seawater	0.001

NOTE: Data were taken from several sources and averaged.

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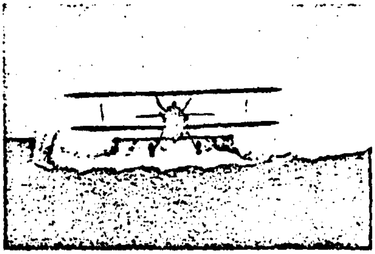
fish catches in the open ocean have not changed for as long as Institution scientists can remember. There are fewer sharks now than fifteen years ago, but this can be blamed on the tuna long-lining industry. Also, few haddock are left on Georges Bank, but as a result of reckless overfishing. Marine mammals and sea birds do appear to have been adversely affected by DDT and PCB. California sea lion cows have shown an increased incidence of delivering premature pups while concentrating very high body levels of DDT and PCB from their environment. When a massive wreck of guillemots occurred in the Irish Sea in 1969, investigators initially concluded that PCB toxicity probably could not be blamed. More recently, however, after having collected additional data, they determined that the dead guillemots had about twice the PCB concentration of healthy birds collected in the same area, and that PCB was the cause of the wreck.

Data collected during observations of a colony of terns near Long Island have shown a correlation between deformed chicks and PCB levels. DDT and mercury concentrations in the terns did not correlate with the incidence of deformed young as well as did PCB levels. Recent work at the Marine Biological Laboratory in Woods Hole demonstrated that sewage applied to a marsh in various amounts caused aberrant behavior and death among the fiddler crab population. The DDT fraction of an extract of the sewage produced the same effects. Also, the various species in a population of marine algae treated with environmental levels of PCB in a laboratory culture system gradually shifted to a few dominant species, although the total biomass remained constant.

In each case cited above, there is an apparent causal relationship between the observed effect and the presence of DDT and/or PCB. However, there is no absolute proof because many other chemicals were also present. Unfortunately, by the time such proof could be demonstrated, irreversible



DDT residues are transported to the ocean via rivers (surface runoff) and atmosphere. Routes of atmospheric transport include aerial drift during application, and vaporization from soil and plants. (EPA-Documerica, Charles O'Rear)

damage could be done to a whole population. We therefore cannot delay installation of control programs until the harmful effects of chemicals in the sea are demonstrated beyond doubt.

The situation may be improving, thanks mostly to pressure from scientific and citizen groups that arose during the late 1960s. DDT has been essentially banned in the United States, except for a few special applications. The use of PCB has been restricted in the United States, Europe, and Japan to products that minimize the possibility of leakage to the environment. Since those restrictions were made, the DDT content of coastal marine shellfish has decreased to a level where monitoring by the EPA has been discontinued. PCB concentrations in North Atlantic seawater have decreased fortyfold since 1972, and there now appears to be a constant, but lower, leakage from the cities to the sea. The response of the marine environment to these restrictions has been more rapid than we anticipated, and most welcome. However, we cannot assume that persistence of any concentration of a foreign substance is harmless to the environment.

Although DDT and PCB levels have decreased to the point where we should be concerned rather than alarmed, research should continue for the following reasons.

In the years ahead, as the world food shortage intensifies, there will probably be massive use of persistent agricultural chemicals because of the favorable economics of spraying only once a year. If we know how these chemicals move in the environment, where they go, and how long they last, we can use them more wisely, with minimal damage to the environment, especially the seas. Furthermore, although PCB and DDT may be phased out of use, other chemicals will have to replace them. New chemicals will find new uses. Rather than being armed with perfect hindsight, we should be prepared with intelligent predictions of possible use patterns and thereby avoid unnecessary pollution of the seas. Finally, it has been very difficult to trace and understand the movement and cycling of organic carbon compounds in the oceans. They can come from land or be synthesized by algae in surface waters. Bacteria can make organic matter or degrade it in surface waters or bottom sediments. Studies of the movements and whereabouts of the chlorinated hydrocarbons DDT and PCB, which originate on land and are not made within the sea, can contribute greatly to our knowledge of the cycling of natural organic matter.

The seas are like a giant, complicated organism composed mostly of water, with some solid materials (dust, fish, whales), all interacting in ways that determine the movements of foreign chemicals through the ocean. We believe the effects of foreign chemicals on ocean life are controlled by regular chemical, physical, and biological processes that we are trying to understand. Only when we understand these processes can we effectively protect the ocean from a premature senility.

George R. Harvey is an associate scientist in the Department of Chemistry, Woods Hole Oceanographic Institution.