of CFCs have contributed:

- Apparent oxygen utilization rates from the central Arctic that are so high, they need to be balanced by transport of high production water from over the continental shelves.
- Quantification of moderate biological consumption and initially low oxygen concentrations in the Arabian Sea are needed to maintain the low oxygen layer.
- Calculation of denitrification rates for the Arabian Sea and Bay of Bengal.

Conclusions

The advantage of oceanic tracers like CFCs is that they can be used to provide timescale information for oceanographic processes. Direct application of the timescale information from the CFCs is used to calculate fluxes of atmospheric constituents, such as CO_2. The oceans have taken up a considerable portion of the anthropogenic CO_2 released to the atmosphere. A large part of the uptake involves water mass formation in high latitudes. The rate at which these waters are transported into the interior will have an effect on the rate at which anthropogenic CO_2 is taken up.

See also

Abyssal Currents. Air–Sea Gas Exchange. Carbon Dioxide (CO_2) Cycle. Current Systems in the Atlantic Ocean. Current Systems in the Indian Ocean. Current Systems in the Southern Ocean. Nitrogen Isotopes in the Ocean. Ocean Subduction. Thermohaline Circulation. Tracers and Large Scale Models. Tritium–Helium Dating. Water Types and Water Masses. Wind Driven Circulation.

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CHLORINATED HYDROCARBONS

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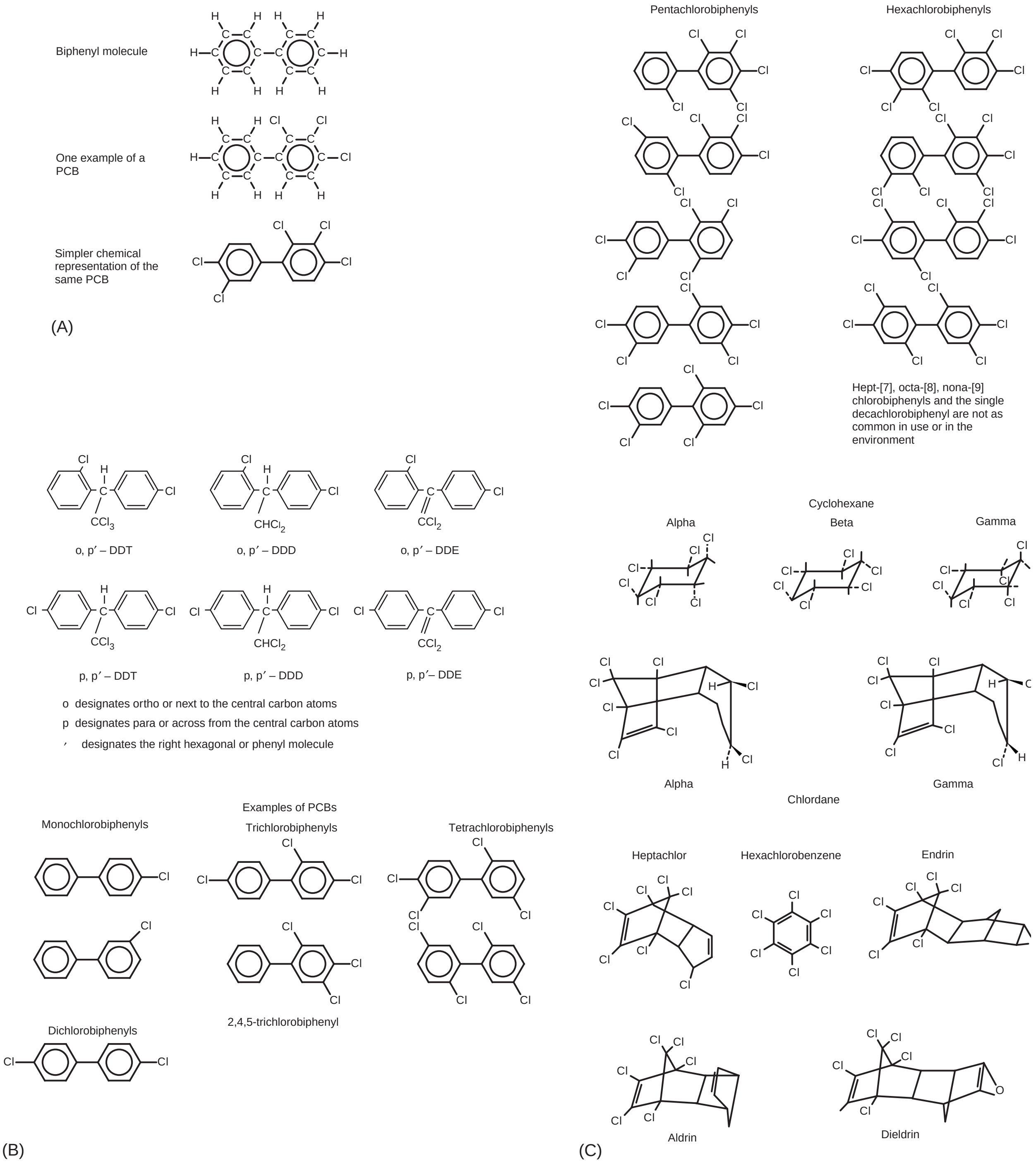
Introduction

These chemicals are considered in a pollution category because both deliberate and accidental release to the environment of several of these types of compounds, for example the industrial chemicals such as PCBs (polychlorinated biphenyls) and the chlorinated pesticides *p*,*p*′DDT (dichlorodiphenyltrichloroethane; formal chemical name 1,1′-(2,2,2-trichloroethylidene)-bis (4-chlorobenzene)), have had unintended adverse environmental effects on diverse plants and animals and on people. Initially, chemicals such as PCBs and DDT were beneficial to human civilization: PCBs as industrial chemicals allowing economical, safe delivery of electricity, and DDT as a pesticide eradicating vector pests of human health concern and agricultural crop pests. Only after these chemicals had entered widespread use did it become apparent that there were environmental problems, although in hindsight there was evidence of potential problems early in the history of their manufacture and use.

Chlorinated hydrocarbons are chemicals made up of the elements carbon (C) and hydrogen (H) of the combine for the ‘hydrocarbon’ part of the molecule, and chlorine atoms (Cl) substituted for hydrogen where a hydrogen atom was normally bonded to a carbon atom. Examples of structures of chlorinated hydrocarbons are given in **Figure 1**.

Chlorinated hydrocarbons have a wide range of molecular weights (related to size), and complexity, i.e., there are various distinct configurations or arrangements of constituent atoms. For example, there are 209 individual chlorobiphenyls (known collectively as congeners) making up the family of chemicals known as PCBs. Not all of these are present in the commercial chemical mixtures of PCBs, but there are usually 20–50 chlorobiphenyl congeners in a given commercial mixture.

Smaller molecules among the class of chlorinated hydrocarbons, such as tetrachloroethylene, trichloroethylene, and carbon tetrachloride are used for



o designates ortho or next to the central carbon atoms
p designates para or across from the central carbon atoms
′ designates the right hexagonal or phenyl molecule

Hept-[7], octa-[8], nona-[9] chlorobiphenyls and the single decachlorobiphenyl are not as common in use or in the environment

Figure 1 Chemical structures of (A) polychlorinated biphenyls (PCBs); (B) dichlorodiphenyltrichloroethane (DDT) and the metabolites dichlorophenyldichloroethane (DDD) and DDE; (C) other chlorinated pesticides. C, carbon atoms; H, hydrogen atom; Cl, chlorine atom.

activities such as degreasing of machinery and dry cleaning. Presently, these compounds are of environmental concern for the oceans only in the near-shore coastal areas where their presence in sewage effluents and contaminated or polluted ground water interfacing with coastal sea water results in elevated concentrations in coastal waters near sources of input.

Environmental and human health concerns associated with chlorinated pesticides and PCBs have evolved over the past several decades into wider concerns with organochlorine compounds of all types, ranging from those found in plastic trash bags to the chemicals of Agent Orange defoliant used by the United States during the war in Vietnam. Among the chemicals of greatest concern on a per unit amount basis are tetrachlorodibenzodioxins; often the name is shortened in general public use to 'dioxins'. Assessments of risks to human health and wildlife for the various chlorinated hydrocarbon pesticides and industrial chemicals are often expressed relative to tetrachlorodibenzodioxin risks.

There are an estimated 10 000 to 11 000 organochlorines in commercial production and many thousands more may be present, but are as yet unidentified, as by-products of the production. In addition, processes such as chlorination of sewage effluent to kill bacteria, result in active forms of chlorine which react with natural organic chemicals in the sewage to produce a myriad of organochlorines; perhaps hundreds to thousands depending on the effluent and the chlorination conditions. Small amounts of organochlorines are also reported to result from various combustion processes, both natural fires and volcanic eruptions, and human-controlled processes such as incineration of wastes.

Analytical chemical, biochemical and molecular biological methods can detect very low concentrations of these compounds in environmental samples, including marine organisms ($\mathrm{ng\,g^{-1}}$, or about one unit mass of chlorinated hydrocarbon molecule per billion unit masses of tissue molecules), sea water (ng per 1000 liters or kg, $\mathrm{ng\,kg^{-1}}$), and marine sediments (nanograms per gram of sediment, $\mathrm{ng\,g^{-1}}$).

Given the widespread occurrence of these compounds, and the known or suspected adverse environmental and human health effects at elevated concentrations, there is a challenge, as with most chemicals of environmental concern, in establishing a 'safe' concentration in environmental samples. This has stimulated intense debate among environmental activists, the chemical industry, researchers, government officials and the public about the adverse environmental effects and human health risks associated with low amounts of organochlorine compounds, including chlorinated hydrocarbons.

Lessons learned about the environmental behavior and adverse effects of chlorinated hydrocarbons provide guidance about what to expect for the more general class of organochlorine compounds. Much information is available about chlorinated pesticides such as the DDTs (in this article DDT includes *p*,*p*′- and *o*,*p*-DDT and the immediate biodegradation and metabolism products DDE and DDD, see **Figure 1**) and PCBs. Thus, DDT and PCBs are used herein as examples for the larger class of chlorinated hydrocarbons. However, the approach of using examples is pursued with the caveat that movement of each of the chlorinated hydrocarbons through the environment, and biological effects associated with each chemical, are specific in important details for each chemical. Although not discussed further here, it is important to note that these chemicals can and have been used as tracers of general processes acting on naturally occurring organic chemicals in marine ecosystems.

History

DDT

DDT is not a naturally occurring compound. It was first synthesized in 1874 and its insecticidal properties were discovered in 1939. Initial large use of DDT as an insecticide began in 1944 and continued into the late 1960s. It was used with success against vectors of human diseases such as malaria and with dramatic effect in agriculture around the world in controlling insect pests. The environmental problems associated with DDT in terms of adverse effects on nontarget organisms such as birds were brought to popular attention in the highly influential book '*Silent Spring*' by Rachael Carson in 1962. Further studies of DDT in the mid 1960s to early 1970s documented the presence of DDT and several other chlorinated pesticides in marine organisms at all major sectors in the marine food web. Analyses of samples from organisms dwelling in the deep part of the oceans, for example 4000–5000 m depth in the North Atlantic, and from Arctic and Antarctic marine ecosystems contained measurable concentrations of DDT. Evidence of adverse effects on nontarget terrestrial, freshwater and marine organisms, especially birds, resulted in curtailed use or bans on the use of DDT in several developed countries in the early 1970s. The legacy of past releases to the environment is present in marine ecosystems in the form of measurable concentrations of DDT compounds.

In addition, the use of DDT continues in a few countries.

PCBs

PCBs (polychlorinated biphenyls) have been used industrially since 1929. Industrial mixtures of PCBs are known by commercial names, e.g., Aroclors (United States), Kaneclor (Japan), Chlophen (Germany), Sovol (former USSR), Fenchlor (France). PCBs were widely used in insulating fluids in transformers and capacitors, as well as hydraulic systems, surface coatings, flame retardants, inks and other minor uses.

Concerns about human health effects associated with halogenated aromatic compounds such as PCBs and halowax (polychlorinated naphthalenes) date to the 1930s and 1940 with the reports of rashes and liver abnormalities for workers in manufacturing plants and electricians. The identification of polychlorinated biphenyls (PCBs) as chemicals of environmental concern dates to the late 1960s when they were reported nearly simultaneously by three different research groups to be present in seabirds and seabird eggs in three different coastal ecosystems.

Subsequent research in the late 1960s and early 1970s confirmed the widespread presence of PCBs in numerous ecosystems, their relative persistence in the environment, and several instances of known or suspected adverse effects associated with various organisms exposed to and incorporating PCBs into their tissues, e.g., mink and chickens fed on fish or fish meal. In 1968, contamination of rice oil used in food preparation at a location in western Japan by PCBs from a leaking transformer caused human health effects for people who consumed the polluted food; this was designated the Yusho incident. A similar incident occurred in 1979–81 in Taiwan: the Yuncheng incident. Detailed studies of the PCB oil involved in these incidents suggested that some or all of the observed adverse effects may have resulted from the presence of small amounts of chlorinated bibenzonfurans or chlorinated dibenzodioxins.

By 1971, the concerns about human health and environmental impacts led Monsanto, the producer of PCBs in the United States, to a voluntary ban on sales of PCBs except for closed systems use. Monsanto ceased all production in 1977 and there was no large-scale increase in imports. PCBs were banned from production and further use in the United States in 1978. Equipment that already contained PCBs, e.g., transformers, were allowed to remain in use but restrictions were placed on the disposal of PCBs when the equipment was decommissioned. Delegates from 122 countries completed a draft treaty on persistent organic pollutants (POPs) in December 2000. The POPs that were initially addressed and banned from further use include chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, PCBs, hexachlorbenzene, chlorinated dibenzofurans, and chlorinated dibenzodioxins. Limited selective use of DDT for human disease vector control is allowed in some countries.

Distribution in the Marine Environment

Early 1970s

Analyses during the early 1970s of various species of marine biota for DDT family chemicals and PCBs established widespread distribution of these chemicals in many areas of the world's oceans from equatorial to polar regions and to depths of 4000–5000 m in the Atlantic Ocean. Biota with significant lipid (fat) in their body tissues tended to accumulate DDT family compounds and PCBs much more than biota with lower lipid content. Marine mammals and birds accumulated higher concentrations of DDT compounds and PCBs, presumably due to being near the top of the food web (biomagnification of contaminants), and having a high body lipid content (especially for marine mammals and birds).

Analyses of surface seawater samples (both dissolved and particulate) and samples of the atmosphere over the oceans established the presence of low concentrations (ranges of $0.01\text{–}1\,\mathrm{ng\,kg^{-1}}$ water or $0.001\,\mathrm{ng\,m^{-3}}$ of air) of DDT family compounds and PCBs. Very low concentrations and difficulties in avoiding contamination from the sampling ship and the sampling gear made measurement of deep seawater samples problematic. The few deep-water samples analyzed documented that the concentrations of DDT and PCBs were not higher than about $0.001\,\mathrm{ng\,kg^{-1}}$ of water. Confirmatory measurements were not made for years thereafter because of intense debate among chemical oceanographers about how to make reliable measurements for these compounds at very low concentrations in sea water. In contrast, the underlying sediments had accumulated sufficient concentrations, because of sorption on particles and deposition, to allow undisputed measurements of both DDT and PCB in deep ocean surface sediments.

Several surveys and research programs documented much higher concentrations of DDT and PCBs in coastal waters and coastal ecosystems compared to open ocean ecosystems; especially near

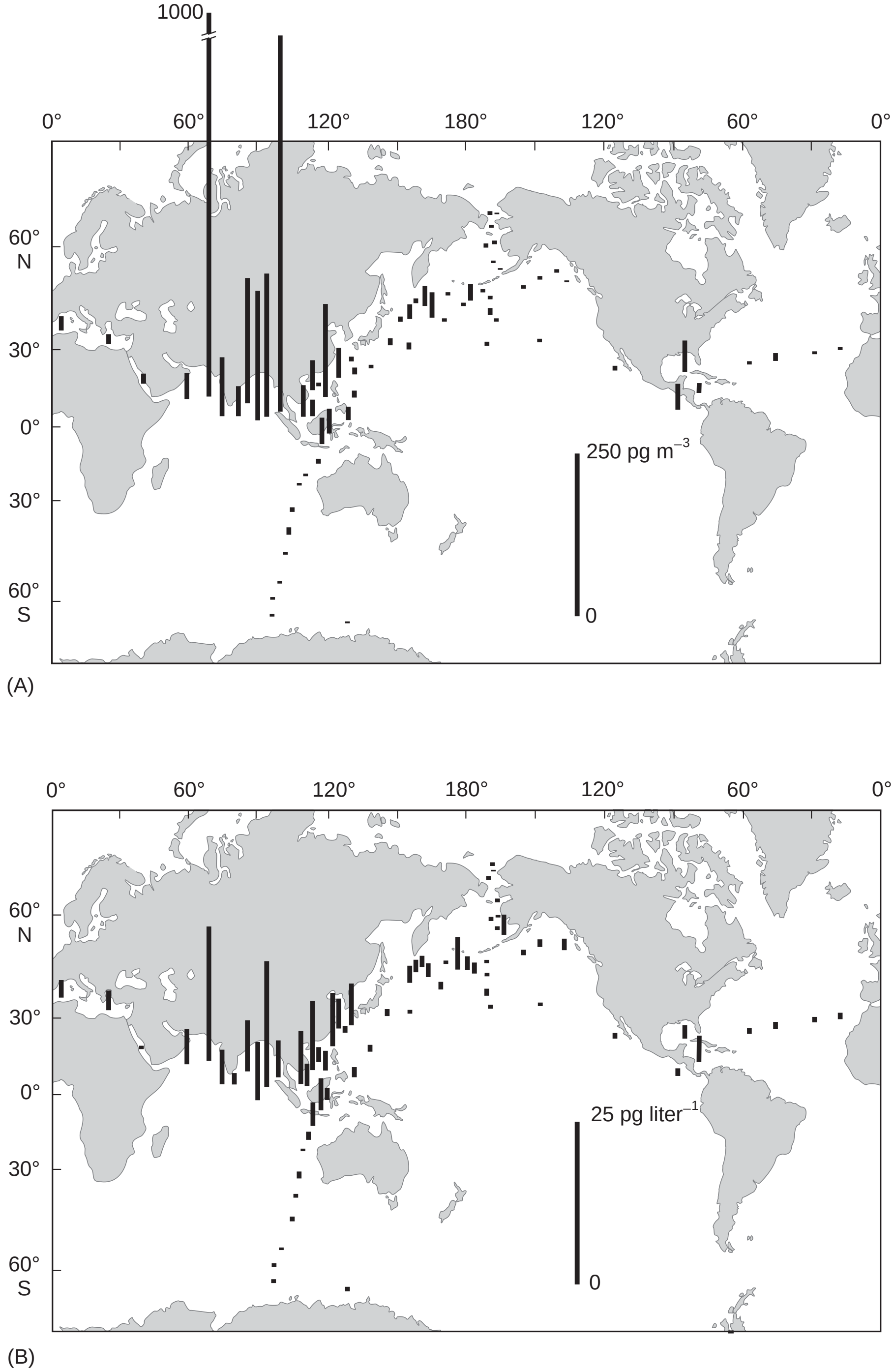


Figure 2 Concentrations of DDT (A,B) and PCBs (C,D) in the atmosphere and surface sea water (B,D) 1989–90. (Adapted with permission from Iwata *et al.*, 1993.)

urban areas for DDT and PCBs, and in coastal regions near agricultural drainage areas for DDT, as might be expected given patterns of use for these compounds and probable release to the environment.

1980s to the Present Day

Open Ocean Recent measurements of PCBs and DDT family compounds in surface sea water and air samples over the ocean on a regional oceanic scale

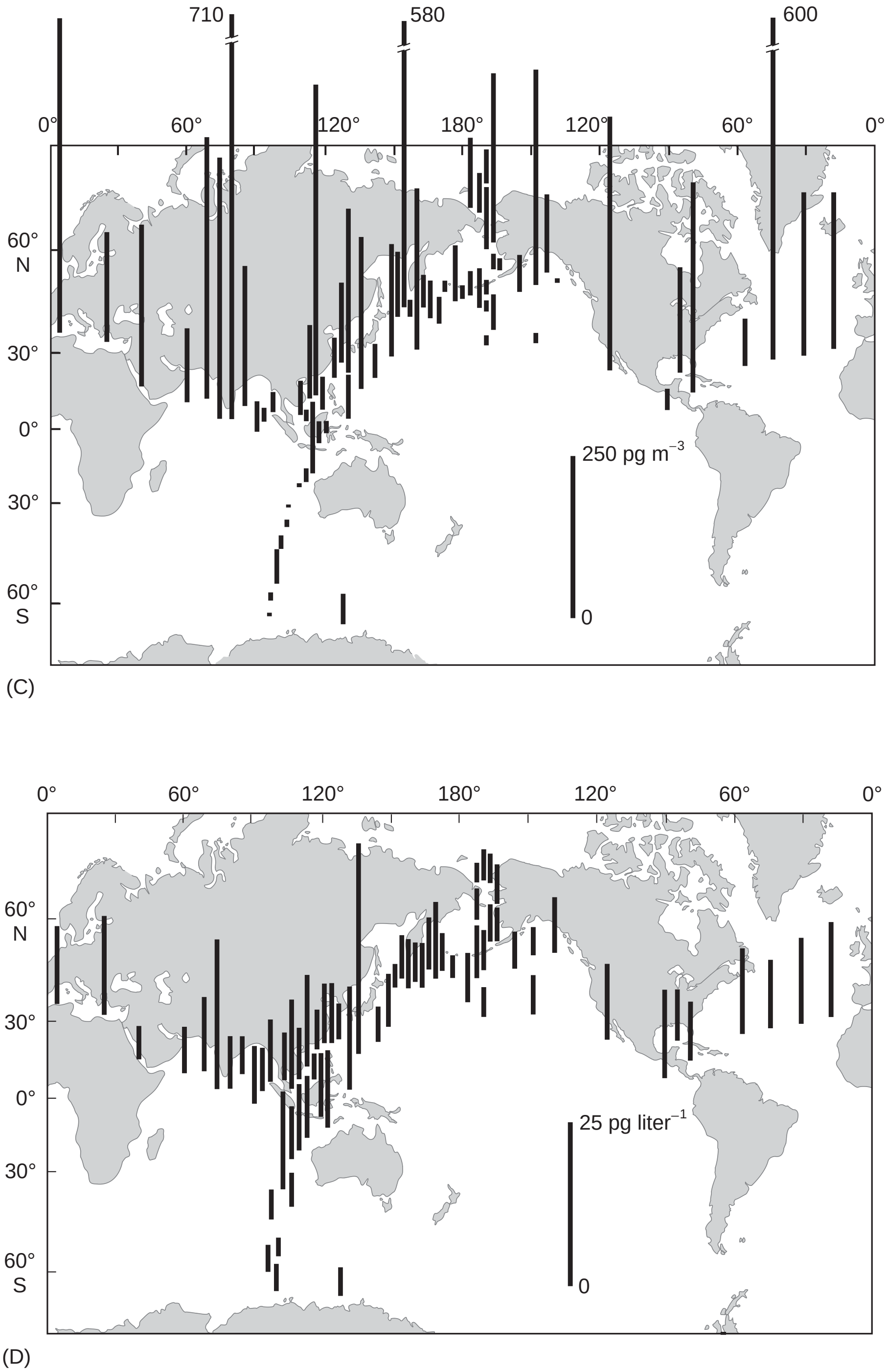


Figure 2 *Continued*

are few and are exemplified in **Figure 2(A–D)**. Despite the paucity of data, some important findings are evident. There are higher concentrations of DDT in surface sea waters and air overlying the oceans near south-east Asia in comparison to the other areas sampled. This is consistent with environmental concerns associated with continued use of DDT in the Asian continent, South Asia subcontinent, and Oceania areas beyond the years when DDT use was curtailed or eliminated in the developed countries of North America, Europe, Japan, and Australia. The PCB concentrations in the surface sea water are in the range of 1–60 pg kg^{-1} and in the overlying atmosphere 3–600 pg m^{-3}. The distribution of concentrations is more even across the areas sampled compared to DDT (**Figure 2**). This is consistent with the continued presence of PCBs cycling in the environment as a result of past releases, leakage from landfills and products containing PCBs still in use, and perhaps continued new uses even though PCB manufacture has been eliminated or severely reduced in many countries.

Recent progress with measuring low concentrations of PCBs in deep ocean waters has enabled a few measurements of deep ocean waters. A depth profile of the sum of concentrations of several chlorobiphenyl congeners for a station in the eastern North Atlantic (**Figure 3**) documents higher concentrations in surface waters with decreasing concentrations with depth as expected due to the greater contact of the surface waters with the atmosphere and contemporary environment. However, all the concentrations are very low in comparison to concentrations found in near-shore waters, lakes, and rivers. Concentrations in the deepest waters are below or at detection limits of the analytical methods used. PCBs in mid-depth and deeper waters are most likely a result of the flux of particles from the surface water carrying sorbed PCBs in and on particles to deeper waters. There has been considerable progress during the 1980s and 1990s in understanding the role and details of particles as conveyers of chemicals from the surface ocean to deep waters and sediments. As the particles sink through the deep waters, desorption and disaggregation of particles and subsequent desorption releases PCBs. Therefore, it is likely, though not proved due to lack of a series of data over time, that current deep water concentrations of PCBs reflect inputs from particle fluxes over the total time of PCB use and release to the environment; for example inputs from peak use in North America and Europe during the 1950s to 1960s.

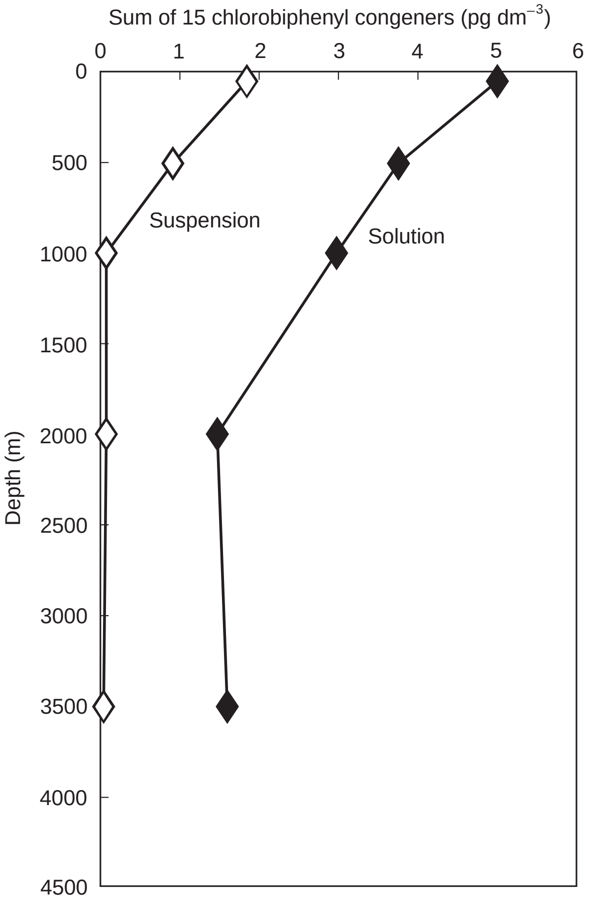


Figure 3 Depth profile of PCB concentrations in sea water, May, 1992. at 47°N, 20°W. Adapted from Petrick *et al.*, 1996.)

Deep-water sediments contain low concentrations of DDT and PCBs in the range of 1–100 ng g^{-1} dry weight or parts per billion. Relatively few deep-ocean benthic (bottom dwelling) animals have been analyzed, but those that have been analyzed contain detectable concentrations of DDT and PCBs in the range of 0.001–1 μg g^{-1} dry weight. Analyses of a few samples of mid-water fish in the deep ocean document the presence of PCBs in a pattern that reflects metabolism of the PCBs after uptake. Although small in numbers of samples analyzed, assessment of fish liver enzymes specific to metabolism of compounds such as PCBs indicate activation of these enzymes and that the fish have responded biologically to the presence of PCBs.

Recent data and an assessment (1993–94) of the flux of PCBs to the North Atlantic open ocean have estimated, as an example, that 14 000 mol year^{-1} of a tetrachlorobiphenyl congener was sequestered in the north-western Atlantic Ocean with 75% of the flux being in the deep-ocean pelagic sector and only 25% in the coastal–continental shelf area. This same assessment provided good reasoning that the flux of PCBs from the atmosphere to the North Atlantic has decreased over the past two decades.

Coastal Ocean Aquatic toxicological studies during the 1960s to the present have established the range of sensitivities of several different species and life stages of marine organisms to chlorinated hydrocarbon pesticides and industrial chemicals such as PCBs. These studies established lethal tolerance limits for these chemicals in aquatic habitats, usually in the microgram per liter range. Such concentrations are rarely encountered today in estuarine or coastal areas, except in the immediate vicinity of exceptional discharges of the chemical. Most current risk assessments for chlorinated hydrocarbons are related to longer term, subacute effects on human health, fish and wildlife feeding on marine organisms. There are various sublethal effects on various organisms that are beyond the scope of this article. They are similar for many types of natural and nonnatural stress on marine organisms and ecosystems. These are summarized in generic form in **Table 1**. However, the caveats below apply, as do the cautions in **Table 1**. Depending on the chemical and the species involved, concentrations in water, sediment, or in the organism's food and tissues eliciting a given effect can range over many orders of magnitude from parts per million to parts per trillion.

The near-shore and estuarine waters of the coastal ocean contain elevated concentrations of DDT and PCBs in comparison to the open ocean. Therefore, attention has been focused on obtaining more data for the coastal ocean. The data sets are more numerous and provide better geographic and temporal coverage for coastal areas of developed countries but much less so for most of the developing countries. Sufficient data have been collected in several areas and sufficient laboratory experiments have been completed to provide a reasonable general understanding of the inputs, fates and effects of DDT and PCBs in coastal ecosystems. **Figure 4** shows a general depiction of the cycling of PCBs in a coastal ecosystem. One key aspect of this biogeochemical cycle is the uptake by animals of DDT and PCBs both from food sources and from water across membrane surfaces such as gills. Exceptions are air-breathing organisms such as birds and marine mammals for which the predominant source is food. Another key aspect of the biogeochemical cycle is sorption of DDT and PCBs onto particles and deposition to sediments. During inadvertent or deliberate discharges or releases to the environment, a portion of these compounds move through coastal ecosystems with portions lost to the atmosphere and transported elsewhere and to be deposited by dust or aerosols, and by rain and snow.

Table 1 General types of responses to PCB contamination for marine organisms. (PCB concentrations in tissues or habitat types eliciting a given intensity of response varies with species and ecosystem)

Level of biological organization	*Types of response*[a]
Biochemical-cellular	Toxication Metabolic impairment Cellular damage Detoxication
Organismal	Physiological change Behavioral change Susceptibility to disease Reproductive effort Larval viability Immune responses
Population	Age, size structure Recruitment Mortality Biomass Adjustments in reproductivity and other demographic characteristics
Community	Species abundance Species distribution Biomass Trophic interactions

[a] Responses are mostly adverse effects, but some are beneficial in offering protection against adverse effects.

Adapted with permission from Farrington JW and McDowell JE (1994) Toxic chemicals in Buzzards Bay: Sources, fates, and effects. In: Costa JE, Gibson V and Pedersen JM (eds) *A Synthesis of Pollutant Inputs to Buzzards Bay.* Buzzards Bay Project Technical Report Series BBP94-30, 18 October 1994. Marion, MA, USA.

Even though the chlorinated hydrocarbons are among the chemicals more resistant to chemical or biological alteration in the environment, there are physical–chemical (e.g., sorption–desorption, transfer from water to air), microbial transformation and degradation, and animal enzyme modifications or transformations, that change the mixture of compounds as the chemicals move through the environment. For example, the mixture of chlorobiphenyl congeners found in a lobster were dramatically different from the original mixture discharged in a nearby effluent from a capacitor manufacturing facility. Those chlorobiphenyl congener mixtures were also different in composition compared to the PCB congener mixture in flounder caught in the same area. The sediment congener mixture for the habitat of both the lobster and flounder had yet another composition. Biological effects of chlorinated hydrocarbons can be specific to each individual chemical in terms of mode of action and potency of action. Thus, the presence of complex and diverse mixtures of these chemicals in various compartments of an ecosystem introduces significant complications to the task of providing an assessment of ecological and human health risks associated with a given site of chlorinated hydrocarbon contamination. In addition, the presence of other chemicals of environmental concern in many of the same areas, means that the present knowledge base is insufficient to provide a high degree of accuracy to a quantitative risk assessment for ecological and human health concerns.

In several coastal areas near urban harbors or major industrial production or use areas, sediments

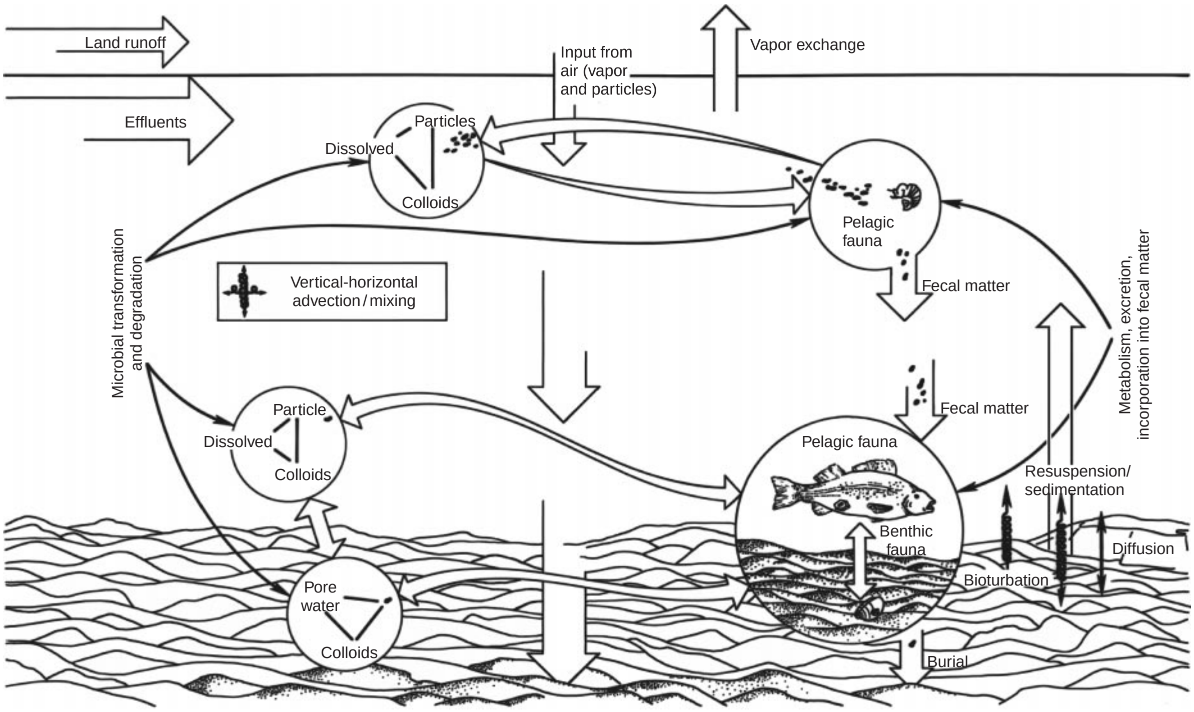


Figure 4 Biogeochemical cycle for chlorinated hydrocarbon pesticides and PCBs in coastal ecosystems.

accumulated high concentrations and substantive amounts of DDT or PCBs. Once discharges were reduced or eliminated with curtailment of production and use of DDT and PCBs, the accumulations of these compounds in sediments continued to be of concern as a source of contamination for coastal ecosystems. The DDT and PCB contaminated sediments can leak REB and DDT or PCBs to the overlying water column or DDJ can be taken up from sediments and water in the spaces or pores between sediment particles (pore waters) by animals living in or on the sediments (**Figure 4**).

Much of the present scientific effort related to DDT and PCBs is focused towards three broad issues: (1) in support of remediation and clean-up of areas of high levels of concentrations as a result of past practices; (2) preventing or limiting mistakes made in developed countries from occurring in developing countries; and (3) tracking the spatial and temporal trends of concentrations of these compounds in marine ecosystems, especially coastal ecosystems.

There are two principal approaches available to track the trend in concentrations over time. One approach is to find areas where coastal sediments are accumulating at a steady and sufficient rate, and are reasonably undisturbed by activities such as mixing of the upper layers by organisms or storm turbulence. Sediments deposited in waters with very low or no oxygen content have limited or no mixing

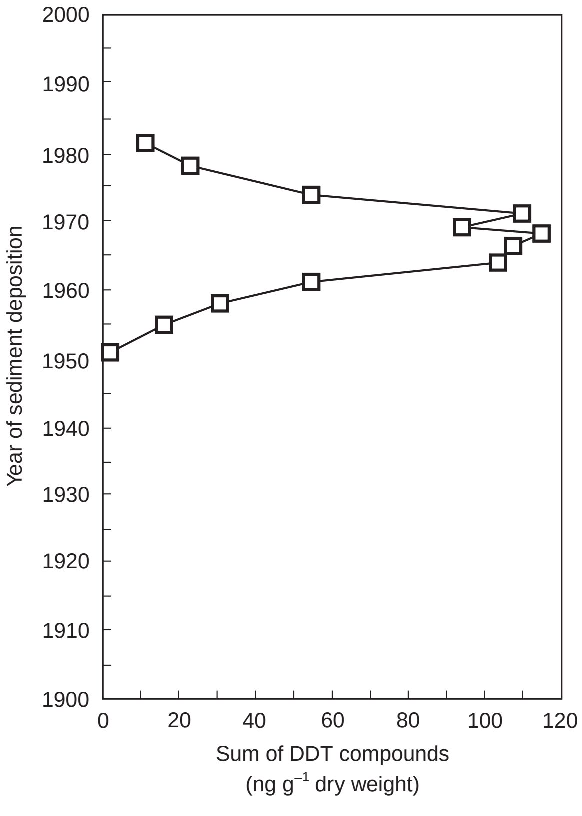


Figure 5 Depth profile of DDT concentrations in San Petro Shelf sediments, Southern California, USA, documenting the historical input of DDT to the area. (Adapted from Eganhouse and Kaplan 1988.)

by organisms and usually meet the criteria. Cores of sediments can be carefully sliced or sectioned at fine intervals and analyzed to provide a historical record, layer by layer, of DDT and PCB concentrations. This has been accomplished with success in several coastal areas, one example being the San Pedro Shelf, Southern California, US coastal area (**Figure 5**).

The other approach that incorporates geographic or spatial assessments with the time series measurements has been incorporated into a monitoring strategy for assessing and monitoring concentrations of several chemicals of environmental concern. This involves the use of bivalves, mainly mussels and oysters, as sentinels of biologically available contaminants such as DDT and PCBs: the 'Mussel Watch' approach. Prototypes of such a program were evaluated in the 1970s in the US, Canada, Europe, and Australia and there are currently several operational programs such as the Mussel Watch component of the US National Oceanographic and Atmospheric Administration (NOAA) National Status and Trends Program.

DDT and PCB concentrations from samples of mussels and oysters obtained between 1986 and 1988 at over 150 stations located around the US

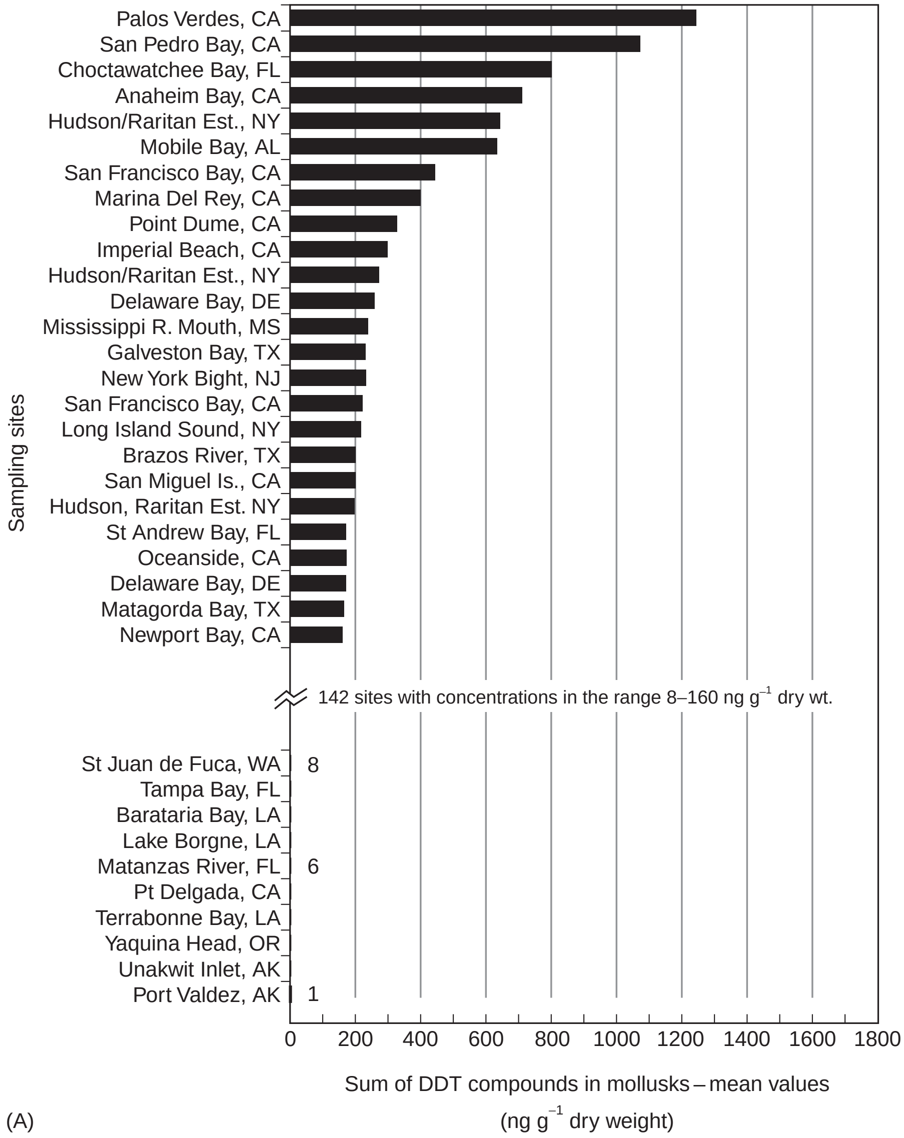


Figure 6 Concentrations of (A) DDT and (B) PCBs in Mussel Watch Stations US NOAA Status and Trends Program (Mussels and Oysters) 1986. (Adapted from *A Summary of Data on Tissue Contamination from the First Three Years (1986–1988) of the Mussel Watch Project*. NOAA Technical Memorandum NOS OMA 49. NOAA Office of Oceanography and Marine Assessment, Ocean Assessments Division, Rockville, MD US, 1989.)

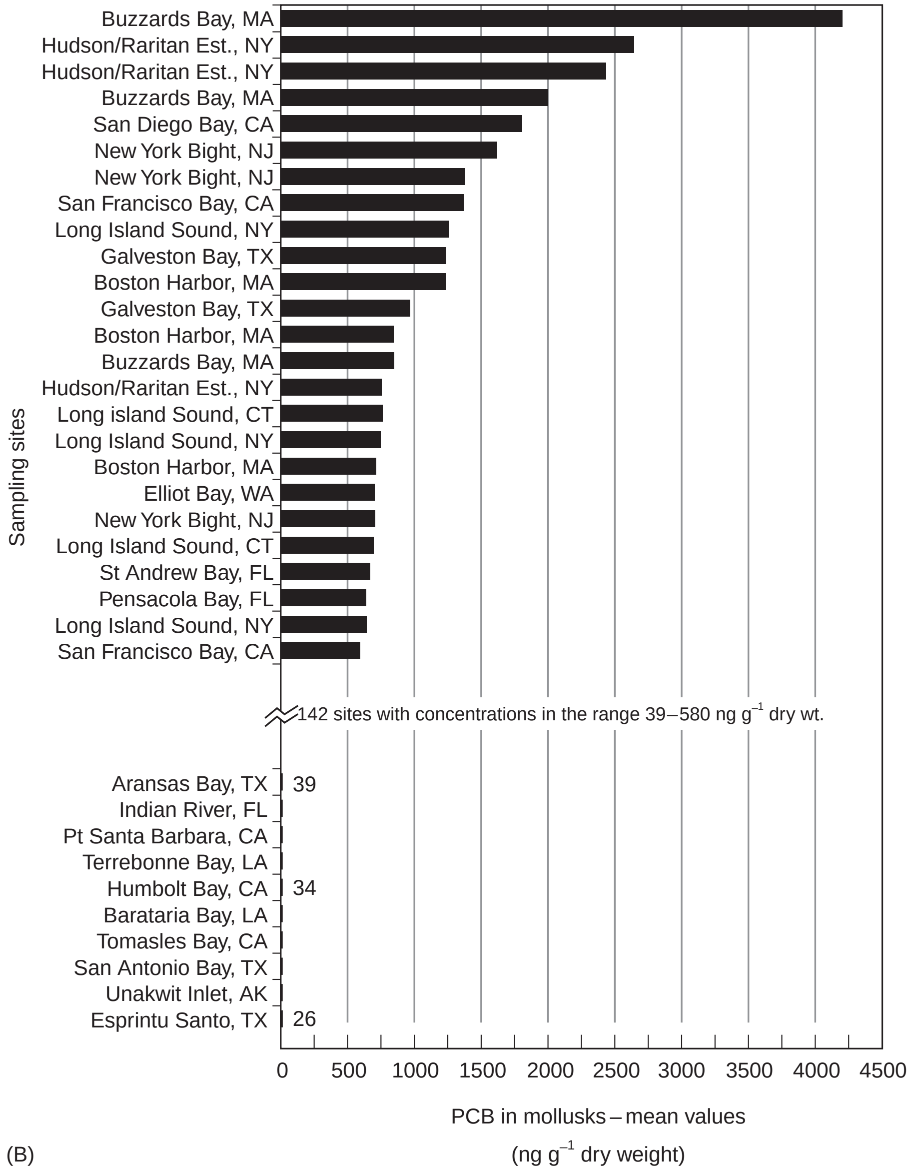


Figure 6 *Continued*

coast are summarized in **Figure 6**. The higher concentrations of both DDT and PCBs correspond to known or suspected sources of inputs from industrial facilities making or using these chemicals, or are near urban areas. Generally it is accepted that concentrations of DDT began to decrease dramatically in portions of ecosystems for some areas of the US coast as a result of curtailed input. Concentrations of PCBs also decreased in the few areas measured during the 1970s and early 1980s as a result of curtailed manufacture and use. The exceptions where concentrations remained elevated were generally in ecosystems with a significant burden of DDT or PCBs in surface sediments as a result of past inputs.

The trends in DDT and PCB concentrations, and two other chlorinated hydrocarbon pesticides, chlordane and dieldrin, in bivalve tissues at locations in the US coastal area for 1986 to 1995 are summarized in **Table 2**. The decrease noted from limited sampling for a few areas in the 1970s and early 1980s continues for some locations. For many other locations, examination of the data indicates that the concentrations are so low that general global and regional biogeochemical cycles are causing only a slow further decrease. A few stations continue to maintain elevated concentrations and for most this can be attributed to continuing contamination of the bivalves from nearby surface sediments containing high concentrations of the compounds.

Table 2 Trends in concentrations of selected chlorinated hydrocarbons 1986–95 in bivalves (mussels and oysters), US coastal areas[a]

Chemical	*Number of sampling locations*		
	Increased	*Decreased*	*No trend*
Chlordane	1	81	104
DDT	1	38	147
Dieldrin	1	32	153
PCBs	1	37	148

[a] Sites of several elevated concentrations are indicated in **Figure 6**. Data obtained from the US Department of Commerce, National Oceanic and Atmospheric Administration World Wide Web Site, October, 2000 http://state-of-coast.noaa.gov/bulletins. Data compiled by Dr Thomas P. O'Connor, US NOAA.

Similar types of 'Mussel or Oyster Watch' data have been collected in some European countries (e.g., France) with similar results. Prototypes of this approach have been carried out in the 1990s for developing countries of Central and South America and South-east Asia under the auspices of UNESCO-IOC and UNEP. Other time trends of DDT and PCB concentrations have been assessed such as concentrations in cod liver oil collected from samples in the southern Baltic Sea from 1971 to 1989 (**Figure** 7). Consistent with the preceding discussion, DDT concentrations decrease by a factor of three to four comparing 1971–1974 with 1987–1989 and PCB concentrations decrease at a slower rate.

The following summary of one aspect of the PCB and chlorinated pesticide saga illustrates the importance of understanding the global, regional, and local biogeochemical cycles of these compounds and their relationship to environmental and human health risks. PCBs and several chlorinated pesticides released to the environment in developed countries of the Northern Hemisphere enter the atmosphere from land and from surface ocean waters in the tropics, subtropics, and temperate zones. Subsequently these compounds are transported by atmospheric circulation patterns to Arctic regions, and enter Arctic ecosystems by precipitation and dry deposition. There may be several cycles of precipitation and volatilization back to the atmosphere before these compounds reach the Arctic. Contamination of the Arctic aquatic ecosystems results in the transfer of these compounds through the food web and biomagnification in marine mammals. Inuits, a native Arctic region or Northern peoples, hunt several of these marine mammals and eat their tissues. The resulting contamination of mother's breast milk transfers these chemicals to infants. There are good reasons to be concerned that subsequent normal development of the children is impaired or slowed. This is the net result of actions of human civilization and complex environmental processes operating over decades and distances of thousands of kilometers.

Conclusions

Humanity was fortunate to learn valuable lessons from early results that indicated widespread regional and global transport of chlorinated pesticides and PCBs accompanied by environmental and human health problems. Much knowledge has been gained about the biogeochemical cycles and about ecological and biological effects of these chemicals in the oceans. This knowledge has been used to guide policy and management actions in many instances. Otherwise, the deplorable situation faced by Inuits might be much more severe and widespread and natural resource populations, including oceanic species, might have been more severely impacted. Despite policy and management actions in many

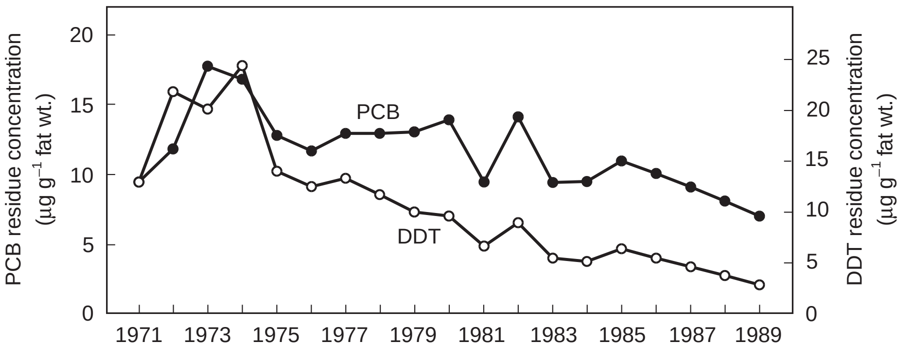


Figure 7 Time trends of DDT (○) and PCB (●) concentrations in cod liver oil from the southern Baltic, 1971–89. (Adapted from Kannan *et al.*, 1992.)

developed countries limiting or eliminating production and release of many of these compounds, there are still concerns about the legacy of past releases to the environment present in coastal ocean surface sediments in several locations. There are serious coastal environmental and human health concerns associated with continued uses of several of these chlorinated hydrocarbons in developing countries.

See also

Crustacean Fisheries. Large Marine Ecosystems. Molluscan Fisheries. Network Analysis of Food Webs.

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CLAY MINERALOGY

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Introduction

Clay constitutes the most abundant and ubiquitous component of the main types of marine sediments deposited from outer shelf to deep sea environments. The clay minerals are conventionally comprised of the $< 2\,\mu m$ fraction, are sheet- or fiber-shaped, and adsorb various proportions of water. This determines a high buoyancy and the ability for clay to be widely dispersed by marine currents, despite its propensity for forming aggregates and flocs. Clay minerals in the marine environments are dominated by illite, smectite, and kaolinite, three families whose chemical composition and crystalline status are highly variable. The marine clay associations may include various amounts and types of other species, namely chlorite and random mixed layers, but also vermiculite, palygorskite, sepiolite, talc, pyrophyllite, etc. The clay mineralogy of marine sediments is therefore very diverse according to depositional environments, from both qualitative and quantitative points of view.