Persistent Lipophilic Contaminants and Other Chemical Residues in the Southern Hemisphere

PERSISTENT LIPOPHILIC CONTAMINANTS AND OTHER CHEMICAL RESIDUES IN THE SOUTHERN HEMISPHERE

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Abstract: Data on the levels of persistent lipophilic contaminants and other chemicals has been reviewed and the dominant persistent lipophilic contaminants in the Southern Hemisphere found to be the chlorohydrocarbons commonly described as the DDTs, HCH's and the PCBs. The distribution patterns suggest that long range transport, probably by global distillation, occurred with these substances. Endosulfan residues appear significant in areas of usage but the data is limited. The data is in accord with a reduction in usage of chlorohydrocarbons in developed countries but an increase in usage in many tropical countries. A systematic comparison of data on the Northern and Southern Hemispheres indicates that the Northern Hemisphere is generally more contaminated than the Southern Hemisphere. It also suggests that the process of equilibration between the two hemispheres is relatively slow. In addition with the HCB's there is an equatorial to polar gradation in concentration probably as a result of global distillation. With the HCH's relatively high concentrations exist in the tropics probably due to their heavy usage in these regions. With the HCB's, DDTs and PCBs the concentrations appear to be more localised in relation to the sources since these substances are less volatile than the compounds mentioned previously.

KEY WORDS: persistent lipophilic contaminants, chlorohydrocarbons**,** endosulfan, global distillation, global contamination, pesticides, southern hemisphere.

I. INTRODUCTION

During the 1960s and 1970s, semivolatile and persistent chlorohydrocarbon pesticides, such as DDT, HCH's, dieldrin and chlordane, and industrial chlorohydrocarbons such as the PCBs and HCB, were detected throughout environmental compartments and were found to be bioaccumulative in lipid-containing tissues (Woodwell *et al*, 1971). These lipophilic substances, having environmental persistence and occurring widely in ecosystems, have been generally described as persistent lipophilic contaminants (PLCs) or persistent organic pollutants (POPs). In addition, there have been detected combustion product residues consisting principally of the polychlorodibenzodioxins (PCDDs) and the polychlorodibenzofurans (PCDFs) which share the persistent, lipophilic and bioaccumulative properties of the chlorohydrocarbons (Rappe et al, 1978). Thus, currently the following substances are usually considered to be globally important PLCs: chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), hexachlorocyclohexane (HCH including lindane), mirex, polychlorobiphenyls (PCBs), PCDDs, PCDFs and toxaphene. Many ecosystems in rivers, lakes, forests, estuaries and agricultural areas have been shown to be contaminated at levels which are considered to be detrimental for many different species of wildlife (Tucker and Crabtree, 1970). In addition, residues of many of these substances have been found to be common in foodstuffs and in human tissues. In recent years, residues of such substances as the polycyclic aromatic hydrocarbons (PAHs), endosulfan, atrazine and many other substances have been detected in many sectors of the environment and share many of the attributes of PLCs (for example Yang *et al*, 1991) thus all organic substances which produce environmental residues have been considered in this review.

Aside from the issue of local and regional contamination from direct usage and disposal of PLCs, investigations and studies in the 1980s and 90s have identified long-range transport through the atmosphere primarily in the northern hemisphere as a mechanism which is important in the distribution of these substances. Recent studies have focused on the global distribution of PLCs and hypotheses such as the “grasshopper effect” have been proposed to explain the nature of the distribution of some PLCs from lower to higher latitudes (e.g. equatorial to polar regions) particularly in the Northern Hemisphere (Mackay and Wania, 1995).

The significance of the usage patterns and distributions of PLCs and other related compounds within countries and geographical regions of the Southern Hemisphere remains much less clear. Several recent studies, however, have collected comparable data on PLCs from regions of the Northern and Southern Hemispheres. Investigations have been carried out in Australia, Southern Africa, South America and the tropical Indo-Pacific area of the Southern Hemisphere which have reported local and regional levels of PLCs resulting from a diverse range of investigations. Various studies of PLCs in human populations from the Southern Hemisphere also exist but are not the subject of this report.

The objectives of this investigation were to evaluate the data available on PLCs and other compounds producing residues in the Southern Hemisphere and relate this to sources, in geographical terms and in terms of temporal changes in usage, and to assess the processes of global distribution.

II. SOURCES AND USES OF PERSISTENT LIPOPHILIC COMTAMINANTS IN THE SOUTHERN HEMISPERE

1. Background

Most of the PLCs of concern are commercially manufactured and distributed as pesticides. For a range of reasons, including a lack of records, categorisation of products and commercial confidentiality, there is a dearth of useful data on manufacture, import and export of PLCs. Available data indicate that whereas DDT has been extensively used throughout the Southern Hemisphere, HCH usage (as distinct from its γ isomer, lindane) has been largely restricted to the Northern Hemisphere, mainly by the former USSR, India and Burma. Historically, South America has been the heaviest user in the Southern Hemisphere of three major PLCs, DDT, toxaphene and lindane. Although the use of DDT is largely discontinued in the developed nations, there is evidence of possible recent use of DDT in many countries in the Southern Hemisphere. Although agricultural chemical uses are often centrally registered, there have been few documented compilations of actual amounts applied. Extrapolation of results from small scale studies, which are available, to large geographical regions may be skewed by differences in practices throughout the region.

PLCs

2. Sources of persistent lipophilic contaminants

With the exception of polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), dioxins and furans, the PLCs of concern are commercially manufactured and distributed as pesticides. The pesticide PLCs are applied to crops, soils, rangelands, forests and to agricultural and forestry products to enhance economic return against the impact of animal, plant and microbiological pest species. The more persistent persistent organic contaminants are also used extensively in protective treatment of wooden buildings against pest damage.

PCBs were used as additives in a wide range of industrial oils and in particular in the electrical industry. This material is still in use, and is being disposed of in insecure landfill or is held in storage awaiting disposal. HCB had limited manufacture as a fungicide, and is now believed to be discontinued. However its continuing major source is as a contaminant in a range of chlorinated products including pesticides and solvents, and in a wide variety of chemical manufacturing processes. It is also a common constituent of flue gases, possibly originating from the combustion of chlorine containing materials. The dioxins and furans are produced by combustion and occur in gaseous and particular emissions.

3. Quality and Availability of Data

There is a lack of reliable information on the manufacture, import/export, and use of PLCs world-wide. Sales figures and import/export data are usually only recorded under broad categories such as “agricultural chemicals” or “pesticides”. Simonich and Hites (1995) noted a general lack of information about the commercial sources of PLCs, and found that only rough estimates were available for a limited number of countries. Voldner and Li (1995) confirmed that data, on present and historical use of persistent chlorohydrocarbons were difficult to obtain and uncertain. Many countries have no central registers for these chemicals with several countries not having a reporting mechanism or record system. Researchers have also found that available data vary in quality and show large spatial and temporal gaps, while in others reporting is in proprietary categories and only composite information is available. For example it is not always clear whether the active ingredient or a mixture is reported.

4. Historical Data on the Usage of Persistent Lipophilic Contaminants

A summary of total global usage of a number of key PLCs derived from a number of sources is given in Table 1. A study by Voldner and Li (1995) has made estimates of historical usage of four key PLCs: lindane, HCH, DDT, and toxaphene. HCH is technical hexachlorocyclohexane (a mixture of several isomers, usually containing more than 50% of the α isomer). Lindane is the γ isomer of hexachlorocyclohexane which has more potent pesticidal properties than the other isomers. Lindane is separated from the technical product, resulting in a more active product with less environmental contamination potential due to the absence of the other isomers but is more expensive. In their study, Voldner and Li (1995) surveyed several world-wide agrochemical data banks, a series of regional studies by UNEP, FAO, WHO and the International Register of Potentially Toxic Chemicals (IRPTC).

Estimates from the study by Voldner and Li (1995) indicate that substantial application of HCH as a pesticide has been restricted to countries north of the equator, with the major users being the former USSR (1000 - 10,000 tonnes), India and Burma (10, 000 - 100, 000 tonnes). In the Southern Hemisphere, only Madagascar had a documented usage (< 10 tonnes).

The other three PLCs, for which usages were quantified by Voldner and Li (1995), were also used more substantially in the Northern Hemisphere, but in addition they have a wide history of usage in the Southern Hemisphere. Figure 1 was based on data from Voldner and Li (1995) by extracting PLC usage data for each country having a major land-mass south of the equator. These figures indicate that South America is the heaviest user of DDT, toxaphene, and lindane in the Southern Hemisphere. Toxaphene has had little documented usage in Africa south of the equator, but DDT has documented usage in substantial quantities in all Southern Hemisphere regions. It should be noted that countries shown as having no usage may have undocumented usage, since the Voldner and Li (1995) study recorded these as having no data available.

5. Overview

There is a general lack of accurate data on global production and usage of PLCs . Estimates to date of usage of PLCs in the Southern Hemisphere indicate that South America is the documented heaviest user of DDT, toxaphene and lindane. DDT has been extensively used in all Southern Hemisphere regions and endosulfan is currently widely used. The data suggest that HCH is not currently used in the Southern Hemisphere. However contamination lingers in regions of former usage.

III. OCCURRENCE AND DISTRIBUTION OF PERSISTENT LIPOPHILIC CONTAMINANTS AND OTHER CHEMICAL RESIDUES

1. Background

The availability of data on PLCs, and other chemicals producing residues, is summarised in Table 2. Other data may be available apart from that cited here, but is less accessible sources. Reports of residue studies on mirex and toxaphene were not found and this appears to be due to their restricted use in Southern Hemisphere environments. Of course the lack of data doesn’t indicate that residues are not present but simply that evaluations may not have been carried out and reported in readily available sources.

Significant data on PLCs in the Southern Hemisphere appear limited to aldrin, chlordane, DDT, dieldrin, heptachlor (heptachlor epoxide), HCB, HCH (α,β,χ,δ) and PCBs. Some limited to very limited data is available on dioxins and furans, PAH’s, endosulfan and atrazine. The herbicide, atrazine, has been reported as persistent in a local region of Australia (NW New South Wales) but other regional studies on atrazine residues are lacking. PAHs are known to be ubiquitous and elevated in urban areas (air, soil, rivers and biota). Our investigation of PAHs indicated that some levels and distributions are available for Australia.

Comparative levels of persistent chlorohydrocarbons in air, seawaters, sediments and biota from the Northern and Southern Hemispheres are available from several international studies (e.g. Iwata *et al*, 1993; 1994; Simonich and Hites, 1995).

2. Air, Waters, Sediments and Soils

Concentrations of chlorohydrocarbons (DDT, HCH, PCBs, HCB, heptachlor & heptachlorepoxide and chlordane) in the atmosphere are summarised in Table 3. In oceanic environments concentrations are generally less than 1 ng/m^3 (1000 pg/m^3) and frequently below 0.1 ng/m^3 (100 pg/m^3). However some elevated levels are associated with Ross Island in Antarctica where a base is established. River and estuarine air levels reported by Iwata *et al* (1994) in the Australasian region are higher and range up to 8.0 ng/m^3, which is probably to be expected since these zones are closer to potential sources compared with oceanic environments. The concentrations of DDTs and PCBs are generally higher than the other compounds detected with the PCBs in oceanic environments exhibiting a maximum of 12.3 ng/m^3 and the DDTs a comparable maximum of 0.240 ng/m^3.

Seawater concentrations for most PLCs (DDT, PCBs, HCH, chlordane and aldrin) are reported for the Southern Hemisphere with the exception of HCB, mirex, dieldrin and heptachlor & heptachlor expoxide (see Table 4). In oceanic regions concentrations are below 0.1 ng/L. Current PCB levels (Iwata *et al*, 1993) are lower by a factor of about 7 compared to earlier values reported by Tanabe et al (1982), for samples collected in similar locations. River and estuarine waters and seawaters in the tropical archipelagos of Indo-Pacific regions tended to be in the range from about 0.1 ng/L to 10 ng/L, particularly for DDT, PCBs and HCHs. Data on freshwater levels (see Table 4) were limited to local river catchments (urban and agriculture) in Australia and South America. Most high values (> 500 ng/L) were measured during the 1970s and early 1980s, but some more recent elevated levels were reported from several rivers in the range of 1-50 ng/L.

Data on aquatic sediments are reported in Table 5 but marine sediments are limited to inshore coastal or estuarine environments. Also the concentrations are generally considerably higher than in the air and water phases. Since partition coefficients from water into sediments can be large, depending on the organic matter content of the sediment, this result is not unexpected. It also suggests that the sediments provide an appropriate phase in which to monitor those contaminants.

It is interesting to note that all of the PLCs in the chorohydrocarbon group, except toxophene, endrin and mirex, have been detected in sediments. DDT, HCH and PCB concentrations were in the parts per billion range to part per million range, i.e. 1-1000 ng/g. However, reported values were based on either dry or wet weight basis which makes comparisons difficult. Generally higher levels of these compounds were found in urban estuarine environments. High concentrations have also been reported for sediments in Australian agricultural freshwater areas (up to 11.3 μg/g DDT), in Antarctica marine area (up to 4.3μg/g PCB), Argentine lakes and rivers (1.86μg/g HGH) and Australian river areas (up to 0.41 μg/g dieldrin). High levels of HCB were reported for marine sediments up to a level of 0.871 μg/g near the Sydney ocean outfall at Malabar. Exceptional levels of DDT up to 118 μg/g, dieldrin (up to 22.8 μg/g) and aldrin (up to 4.1 μg/g) were measured in Lake Kariba, Zimbabwe.

There was a trend for the higher concentrations to be reported during the 1970’s and 1980’s with lower concentrations being currently reported. An exception to this is the HCB reported from Sydney, Australia which probably originates from industrial sources.

Soil data, however, were limited to certain areas of Australia. As expected levels of contaminated soils (DDT, dieldrin, heptachlor, chlordane, HCH) ranged from about 10 ng/g to 10, 000 ng/g with pasture levels under 100 ng/g. Soil levels are likely to vary with land use activities.

The PAH's are usually not considered to be PLCs but Table 6 indicates relatively quite high concentrations of these substances are widely distributed throughout the environment. The sediment levels reported for an Australian area and the Antarctic are comparable with the levels of many PLCs . The capability of these substances to distribute in the environment is probably less than the chlorohydrocarbons due to their relatively lower persistence. Endosulfan is worthy of specific consideration since it is currently used in major quantities (see Table 1) but it is less bioaccumulated and persistent than the chlorohydrocarbons considered as PLCs. Available data on endosulfan is tabulated in Table 7. The concentrations are generally less than those of DDT and PCBs in biota and sediments but in many cases exceed the levels of other PLCs.

3. Biota (Marine and Terrestrial)

Reported concentrations of PLCs in aquatic organisms for locations in the Southern Hemisphere are compiled in Table 8. Most data seem to reflect specific studies in areas where urban and/or agricultural activities are known to result in release of such substances to the environment. Some data refer to sedentary organisms such as many invertebrates, but many species are mobile, e.g. species of fish. Residue data for aquatic organisms tend to range from a part per billion (1 ng/g wet weight) to the low parts per million or more (over 1000 ng/g wet weight) for urbanised estuaries, bays and near coastal outfalls as shown in Table 8. A range of relatively high concentration is apparent with Australian invertebrates and fish exhibiting concentrations up to 40.3 µg/g DDT. However this data is generally derived from the late 1960s to early 1980s. Also, some high concentrations have also been reported for Antarctic invertebrates (up to 0.43 µg/g PCB), Australian invertebrates (up to 5.0 µg/g PCB), Argentinean fish and bivalves (up to 5.8 µg/g PCB), Australian fish (up to 6.0 µg/g dieldrin), Argentinean species (up to 2.0 µg/g heptachlor and heptachlor epoxide). Australian fish species (up to 1.7 µg/g chlordane). In oceanic environments removed from known sources, there are detectable but contain low levels of many of these compounds e.g. fish in the Eastern South Pacific up to 0.33 µg/g PCB and fish in the South Atlantic up to 0.02 ng/g heptachlor and heptachlor epoxide.

Databases which contain comparable measurements of PLCs within biota from the Southern Hemisphere are limited to chlorohydrocarbons, and closely related substances, using terrestrial vegetation as a substrate. Simonich and Hites (1995) determined the global distribution of a range of PLCs and related compounds (excluding PCBs) in tree bark samples (200) from 90 sites world-wide. Chlorohydrocarbon and endosulfan residues tend to range between 10 and 1000 ng/g lipid with several higher levels 1000 - 10 000 ng/g lipid in urbanised areas of Australia, South Africa and South America (DDT, endosulfan and HCH). HCB levels were lowest, around 100 ng/g or less, whereas endosulfan was evident in the 100 to 1000 ng/g lipid range. Simonich and Hites (1995) concluded that the distribution of the relatively volatile chlorohydrocarbons, e.g. HCB, increased with latitude which was not the case for endosulfan.

Calamari *et al* (1991) analysed mango leaves, pine needles, lichen and moss from 26 sites world-wide (see Table 9). Individual compounds ranged between 0.1 and 10 ng/g on a dry weight basis. Total DDT and HCH residues were highest in Southern Africa where most of the samples were collected for the Southern Hemisphere. In addition, Tremolada *et al* (1993) found relatively high concentration in the Southern Indian Ocean.

Chlorohydrocarbons PLCs have accumulated in a wide range of marine mammals (cetaceans and pinnipeds) living in waters throughout the Southern Hemisphere (see Table 10). Concentrations of PCBs (up to 15.5 μg/g) and DDT (up to 28.4 μg/g) have been found in the blubber of some species, e.g. dolphins, off the South African and Australian coasts. Lower levels of chlorohydrocarbons, such as PCBs, are reported for Antarctica (see Table 10).

Critically, the majority of reported data on marine mammals refer to the 1980s or even earlier. Trends in levels are consequently difficult to analyse. de Kock *et al* (1994) found little significant change in PCB levels in dolphins from the West Coast of Africa, sampled during the 1970s to 1986-7. Bacon *et al* (1992) concluded from their study of chlorohydrocarbons in pinniped milk, that seals and sea lions from the Arctic (northern fur seals) and California (sea lions) have higher levels of chlorohydrocarbon pesticides and PCBs than from either the Antarctica (fur seal) or Australia (sea lion).

IV. RELATIVE PERSISTENT LIPOPHILIC CONTAMINANT CONTAMINATION IN NORTHERN AND SOUTHERN HEMISPHERES

1. Temporal Changes in Persistent Lipophilic Contaminants Usage

An important factor in considering PLC contamination is that usage has changed with time especially in the last 10 years. These changes are reflected in both reduction and increases in levels of PLCs detected around the globe and also in a general change in PLC usage related to climatic zones. During the last decade, the production and use of HCHs and DDT have been restricted or banned in many countries (Forget, 1991; Iwata *et al*, 1993; Iwata *et al*, 1994; Voldner and Li, 1995). The effects of this action are reflected in such results as those produced by the Mussel Watch program which show that the levels of DDT in Southern USA around the Gulf of Mexico have declined from 1986 to 1993, and are now relatively uniform in concentration (Sericano *et al*, 1995). The usage of these substances, however, is still widespread in many tropical countries such as India and some Asian countries (Iwata *et al*, 1993; Iwata *et al*, 1994; Voldner and Li, 1995). This usage pattern is believed to be the cause of contamination of tropical regions with certain PLCs , and the source of some PLCs in temperate and polar regions (Iwata *et al*, 1993; Iwata *et al*, 1994).

The concentrations of PLCs in the oceans of the mid-latitudes in the Northern Hemisphere have also decreased since the early 1980s, probably as a result of decreased use of these compounds in regions and countries such as Japan, USA and Europe (Iwata *et al*, 1993). The present distribution of certain PLCs in the world's oceans also suggests a change in contamination patterns during the last decade (Iwata *et al*, 1993).

The temporal trends of contamination vary significantly with location and time period. For instance, the period from 1988 to 1992 showed larger concentrations of HCH in ecosystems of the Russian Arctic and Russian Far East, but significant decreases in PCB concentrations during this period (Chernyak *et al*, 1995). A study of the levels of chlorohydrocarbon pesticides in Arctic lake sediments (Muir *et al*, 1995) has shown that DDTs and chlorobenzenes in these sediments reached maximum concentrations during the late 1970s to the 1980s, which is about 5 to 10 years later than Canadian lakes, thus suggesting a lag time for transport to the Arctic.

In the Southern Hemisphere, a pattern of decline of HCH contamination in air and water has been shown for the period 1975 to 1985 (Tatsukawa *et al*, 1990). On the other hand, Kurtz and Atlas (1990) found concentrations of total HCH in the Coral Sea near Australia and New Guinea to be approximately 5 to 10 times higher than those measured in 1981, with concentrations in the more recent investigation reaching several thousand pg/L. The mechanisms of this temporal increase however were not elucidated.

In contrast, levels of DDT in South American countries have a much greater range of concentrations, with results for some areas suggesting continued usage of DDT (Sericano *et al*, 1995). The levels of chlordanes and PCBs also reflected these trends, with a general decline of concentration in southern USA and localized high concentrations in some South American locations (Sericano *et al*, 1995).

In general, it appears that HCHs are prevalent in tropical Asia, which is a current source, and in higher latitudes; DDTs are located at elevated levels in tropical countries according to use; and chlordanes and PCBs more uniformly distributed globally (Iwata *et al*, 1993; Iwata *et al*, 1994).

2. Comparison of Northern and Southern Hemisphere Contamination

It is difficult to make valid comparisons between the Northern and Southern Hemispheres due to differences in such factors as : (1) specific local contamination situations (2) latitude (3) the nature of the sample taken and (4) the sampling time. By taking these factors into account it is possible to make comparisons and evaluate trends. In this way the available sets of data were evaluated in terms of the factors mentioned previously allowing pairs of data sets (Northern and Southern Hemispheres) to be selected as a basis for comparison as described in the following discussion.

Hexachlorobenzene (HCB) and Hexachlorocyclohexane (HCH) In the case of HCB in plant biomass (see Figure 2) it can be observed that polar areas are higher in HCB with tropical areas in both hemispheres being below the limits of detection (<0.1 μg/g dry weight). This is presumably due to the volatility of HCB and its consequent movement towards the poles, and condensation in the colder region. Also polar and temperate regions of the Northern Hemisphere appear to be higher in HCB residues than corresponding areas in the Southern Hemisphere.

In the case of the HCHs , the available data suggests an influence of latitude on concentrations in both the abiotic environments, and plant biomass. The usage of HCH in the tropics (Iwata *et al*, 1993), especially in the Northern Hemisphere tropical countries, appears to be responsible for the relatively higher concentrations of HCH in tropical areas. In the recent paper of Simonich and Hites (1995), it has been shown that a correlation exists between latitude and concentrations of HCH and HCB in tree bark samples. The data also show, however, that the highest concentrations of these PLCs occur in the Northern Hemisphere. In addition, it has been shown (Calamari *et al*, 1991; Iwata *et al*, 1993) that much higher levels of the HCHs occurred in the Northern Hemisphere. This is obviously due in part, at least, to extensive sources of input in the Northern Hemisphere, with areas such as the Arabian Sea and Bay of Bengal having concentrations of HCHs in atmospheric samples of over 10 000 pg/m^3 (Iwata *et al*, 1993).

The levels of HCHs in the ocean atmosphere and hydrosphere around Australia and the Southern Ocean have been shown to be significantly lower than those in the Northern Hemisphere (Tatsukawa *et al*, 1990) for an eleven year period to 1985. In contrast, however, are the findings of Weber and Montone (1990), and Kurtz and Atlas (1990). Weber and Montone (1990) found that the levels of HCHs were of the same order of magnitude in air over the Southern Ocean as in other world oceans. These authors, however, stated that the quantitative results could be regarded as only tentative. The results of Kurtz and Atlas (1990) show that the levels of HCHs in ocean water in the Coral Sea to the east of Australia and Papua New Guinea are elevated and could possibly arise as a result of surface runoff. This area is regarded as a possible hotspot and not an indication of general contamination of the Southern Hemisphere.

Polychlorinated Biphenyls (PCBs) : The levels of PCBs in various sample types appear to depend largely on the influence of local sources of contamination. Many cases of PCB contamination are hotspots and consequently hemispherical patterns of distribution are difficult to determine from available data. PCBs in general are less volatile than HCHs and HCB and consequently are less influenced by the global distillation process. It has been estimated however (Tanabe and Tatsukawa, 1986), that the Northern Hemisphere ocean environment contains about 150,000 tons of PCBs which is about two thirds of the global load. These authors have also found that significant concentration differences exist between the Northern Hemisphere and Southern Hemisphere oceans with respect to overlying air, water, sediments, plankton, fish and mammals. In these studies, the Southern Hemisphere ocean environments were found to be lower in PCBs.

DDT: A similar situation is observed with DDT as with the PCBs where obvious hotspots occur, in particular in areas surrounding developing countries in the tropics. Data from marine pinnipeds (see Figure 3), however, show that DDT contamination in these biota is higher in the Northern Hemisphere than in the Southern.

Chlordanes: The concentrations of chlordanes also reflect the effect of usage, with areas of contamination around the globe. Areas away from obvious contamination show more uniform levels in various samples. The data for pinnipeds however reveal that chlordanes are bioaccumulated to higher levels in the animals from the Northern Hemisphere with up to 2,800 ng/g lipid in Northern Hemisphere animals compared to up to 69 ng/g lipid in Southern Hemisphere animals.

Endosulfan: This substance does not seem to be globally distributed since it has not been reported from locations remote from sources and concentrations are generally location specific and depend on local usage patterns. Gregor and Gummer (1989) however, have found that α-endosulfan was the second most abundant POP in Arctic snowpack. Possible explanations are the detection of an artifact in this study, or the failure of most other studies to analyse for endosulfan.

3. Interhemispheric mixing of PLCs

The effects of atmospheric circulation patterns and oceanic currents are important in understanding the role of interhemispheric mixing on the global distribution of PLCs. For instance, it is widely accepted that global distillation is a major process involved in the deposition of volatile PLCs such as the HCHs at the poles (Wania and Mackay, 1995). Barrie *et al* (1992) however, have concluded that both the atmosphere and the ocean currents are the major transport mechanisms which must operate in conjunction with global distillation for the movement of PLCs to the Poles.

Important findings from the work of Levy (1990) are: atmospheric transport in the east-west direction will increase with height; air parcels will subside in the tropics; and air passing between hemispheres will rise in the tropics and be exposed to precipitation produced by the lifting of the moist tropical air. It should be noted that the prevailing east-west winds are generally from the east in the tropics and from the west at higher latitudes. The north-south winds provide a more complex situation, but the velocities seldom exceed 1 m/sec. (Levy, 1990).

In the Southern Hemisphere, the prevailing winds are the south-easterly trades which thus blow towards the Equator. During spring and summer however, periods of predominantly northerly winds can occur to the east of troughs. Despite times of northerly winds over Australia and other parts of the Southern Hemisphere, little interhemispheric mixing occurs due to the presence of Hadley cells over the tropics (Levy, 1990). The thermally directed Hadley cells produce a strong upward flux in the tropics and subsiding flux in the subtropics, with little consequent interhemispheric mixing.

It appears that as a general rule, PLCs are lifted in the atmosphere in the tropics, and move polewards due to the global distillation effect, but because of the presence of Hadley cells in the tropics and very low north-south velocities, little interhemispheric mixing occurs. Irrespective of season, on a global basis, the major feature is a converging surface flow in the tropics that is coupled to a vigorous rising motion in the region that results in strong precipitation. This region has been called the intertropical convergence zone (ITCZ) (Levy, 1990) and forms a strong barrier to transport of chemicals between the hemispheres.

The effect of ocean currents on interhemispheric mixing has the potential to be important through direct movement and since a flux of contaminants between the atmosphere and ocean surface water occurs (Iwata *et al*, 1993). The potential for interhemispheric mixing varies between PLCs. For instance, HCH concentrations in surface water are highest in the high latitudes of the Northern Hemisphere (Iwata *et al*, 1993), and significant mixing would not be expected to occur. In contrast, the highest levels of DDTs are in surface water in tropical Asia (Iwata *et al*, 1993; Iwata *et al*, 1994), and offer a potential for contamination of the Southern Hemisphere.

A consideration of the ocean currents of the world indicates that the major currents in the Southern Hemisphere circulate in an anticlockwise direction and in a clockwise direction in the Northern Hemisphere. The Pacific, Atlantic and Indian equatorial counter currents run from west to east around the equator while the Pacific North and South, Atlantic North and South, and the Indian South Equatorial currents all run to the west above and below the equator. This situation does not facilitate significant mixing of Northern and Southern Hemisphere waters.

The work of Iwata *et al* (1993) has shown that atmospheric PCB concentrations have not decreased rapidly since the 1980s. Tanabe and Tatsukawa (1986) have estimated that the oceans contain the majority of PCBs, and that the oceans of the Northern Hemisphere contain approximately 183,000 tonnes of PCBs while those of the Southern Hemisphere contain approximately 47,000 tonnes. When it is considered that most PCB releases declined after the 1970s, it is apparent from the figures of Tanabe and Tatsukawa (1986) that interhemispheric mixing has not occurred to an appreciable extent with PCBs.

VI. ASSESSMENT OF PERSISTENT LIPOPHILIC CONTAMINANTS BY REGIONS AND COUNTRIES OF THE SOUTHERN HEMISPHERE

Australia

Australia has a history of intensive use of chlorohydrocarbon insecticides, HCB and PCB but there has been a gradual phasing out of the chlorohydrocarbons, through restrictions on agriculture use. Also, in 1972, the fungicide HCB was withdrawn from use and prohibited but was still produced as an industrial by-product in chemical manufacture (see Selinger, 1995). Importation of PCBs, including in equipment, was banned in 1975 although enclosed use has been allowed to continue up to the present date.

The use of cyclodienes (e.g. heptachlor and chlordane) for termite control has been recently banned or withdrawn from sale (aldrin and dieldrin) and is being replaced by alternative chemicals, e.g. chlorpyrifos and synthetic pyrethroids, and physical barriers. However, high levels of these types of compounds exist in soils under and around "treated" buildings. Endrin residues appear to be negligible and this pesticide has not been used since the 1970s. Toxaphene and mirex residues have not been reported in the many available Australian surveys.

HCB concentrations in urban Australian areas appear to have declined. This conclusion is supported by results of Australian Market Basket Surveys of dietary intake. Tree bark levels produced by Simonich & Hites (1995) were in the lower 10 to 100 ng/g lipid range. Iwata *et al* (1994) did not report any data on the occurrence of HCB. Significantly, high levels of HCB were found in sediments (mean 871 ng/g) offshore from one of Sydney's sewage outfalls at Malabar. Major production of HCB and storage of wastes occurs at Botany Bay, Sydney. There are no data for grain growing areas where HCB was used as a fungicide.

PCBs also appear to have declined substantially since imports were restricted and waste management practices introduced. Unpublished data on the Brisbane River shows a substantial decline in water and sediment residues from earlier monitoring in the 1970s by the Queensland Water Quality Council. Also DDT levels were relatively high in early Australian studies and some residual levels remain since registered uses decreased in the early 1980s and DDT was phased totally out of use in 1987. Iwata *et al* (1994) found estuarine sediment levels of up to 1700 ng/g dry weight and tree bark analyses have indicated persistent contamination. The cyclodienes, such as dieldrin, remain as residues through previous agricultural use and more recent use (aldrin and heptachlor or chlordane) as termiticides. Government agencies suggest dieldrin residues in estuaries have declined substantially.

Chlordane (and heptachlor epoxide) appears to be present in urban areas where it has been used for soil treatment and insect control.

Endosulfan is highly toxic to wildlife and considered low in persistence and bioaccumulation capacity. Even so, residues have been reported in areas of usage (see Table 7) and measured in tree bark samples (100-1000 ng/g lipid range). HCH (technical BHC and lindane) based insecticides were de-registered in the mid-1980s except for sugar cane usage in Queensland. Low residues were detected in coral reef organisms along the Great Barrier Reef in the 1970s. It is likely that some residues remain in caneland soils. Iwata *et al* (1994) found estuarine and river sediment levels from 0.018 to 17 ng/g and tree bark samples were generally low. The herbicide, atrazine, has also been reported (Department of Land and Water Conservation, 1995) as a persistent residue in north-western New South Wales where there is intensive agriculture, particularly grain and cotton growing.

Total PAHs in seawaters on the Great Barrier Reef (GBR) were less than 1 part per billion while sediment levels ranged from 570 to 1137 parts per billion (ng/g) (Table 6). Clam species from the GBR contained much lower levels of Total PAHs (<0.025 - 6.72 ng/g) reflecting PAH levels in the more pristine reef waters. PAHs in estuarine waters in the Brisbane River were also less than 1 part per billion (103 - 131 ng/L) but levels were much greater in sediments ranging from 3.9 to 16 mg/kg. Thus, urban runoff and discharges appear to be significant sources of PAHs in this situation.

Australian guidelines for environmental quality in waters (ANZECC, 1992) can be used to evaluate the occurrence of PLCs in Australian waters. It is evident from Table 11 that DDT and dieldrin levels in many marine and freshwaters within Australia would have exceeded these guidelines in the 1970s and early 1980s. Recent measurements of river and estuarine waters show that chlorohydrocarbons in Australia are generally at acceptable levels except possibly for elevated PCB levels around Sydney. Endosulfan levels in rivers draining irrigated areas of north western NSW are at levels above the standard in Table 11 and PAHs in urban areas (see Table 6) can greatly exceed the guidelines (see Table 11).

If the ANZECC guidelines for protection of human consumers of fish and other aquatic organisms (see Table 11) are applied to the data for fish and other food organisms, then many fresh and estuarine waters in Australia and other countries are likely to contain compounds above these guidelines.

Southern Africa

There is a paucity of data on PLCs in Southern Africa. The limited data available suggest that generally chlorohydrocarbons in waterways are low but this is not the case for Lake Kariba, Zimbabwe where sediments were contaminated with DDT, from 5.62 to 117.7 µg/g (parts per million) endosulfan (1.91 to 167.8 µg/g)and several other substances (Zaranyika et al, 1994). Uses were for control of tsetse fly, malaria vectors and agriculture. High levels of DDT have been reported in fish, mussels, snails, prawns and birds from this lake system. Levels of DDT in whales from the South African waters were up to 1.22 µg/g (blubber) but PCB levels were much higher in whales and dolphins (up to 15 µg/g, blubber) (de Kock et al, 1994).

Plants (mango leaves) in Kenya, South Africa and Southern Indian Ocean islands contained significant DDT and HCB residues, generally in the 1 to 50 ng/g range although Mauritius had much higher levels, up to 2140 ng/g (Calamari et al, 1991). HCH residues were in the 2-9 ng/g range in Kenya. The tree bark survey indicated that of the chlorohydrocarbons, DDT and HCH and product significant residues in the 100 to 1000 ng/g lipid or greater range for Southern Africa (Calamari et al, 1991). The pattern of PLCs contamination for Southern Africa remains unclear and fragmented. Indications are that the levels are generally lower than developed and tropical countries. This may not be the case in areas where large scale aerial spraying occurs for disease control and intensive agriculture.

South America

Widely published information on PLCs from this region of the Southern Hemisphere is limited and confined to relatively small scale areas or countries such as Argentina, Brazil or Uruguay. Many of the data also refer to the early 1980s. PCB contamination is evident from major urban areas located on estuaries. Mean levels of 15.7 ± 19.2 ng/g were reported in sediment from Rio de La Plata in Argentina and up to 25 ng/g in Brazil (Colombo et al, 1990; Japenga et al, 1988). These levels are generally lower than sediment values reported by Iwata *et al* (1994) for urban Australian areas. Of the chlorohydrocarbons pesticides, HCH levels (α and γ) were relatively high in sediments from rivers and coastal bays in the early 1980s.

Antarctica

Measured environmental levels of chlorohydrocarbons in the atmosphere in the Antarctic region are less than 0.1 ng/m^3 with DDT levels from the Southern Ocean less than 0.01 ng/m^3

and HCH levels tended to be in the range 0.01 - 0.1 ng/m^3 (Larsson *et al*, 1992; Bidleman *et al*, 1993; Iwata *et al*, 1993), (see Table 3). Of special interest are the levels of PCBs. A local source of PCB contamination has been demonstrated at McMurdo Station, Ross Island (Kennicutt *et al*, 1995). Sediment levels (1989-1993) were from 250 to 4300 ng/g (see Table 4) and Minke whales sampled during 1986 in the Antarctica waters were reported to contain low PCB levels, <0.01 - 0.03 µg/g, blubber (Bacon *et al*, 1992; see Table 10). In comparison, DDT levels in marine mammals sampled during the period 1983-1989 contained levels of up to 2.4 µg/g blubber. Oil spills and discharges at Arthur Harbour, McMurdo Base have also caused elevated levels of PAHs in waters, sediments and biota similar to urbanised estuaries and bays.

Tropical Indo-Pacific Region

Data on chlorohydrocarbons for this region are derived mostly from Iwata *et al* (1994) who reported atmospheric levels for PCBs from 0.01 - 0.1 ng/m^3 for Indonesia - Papua New Guinea which was elevated to 1.3 ng/m^3, at Guadalcanal, Solomon Islands. The distribution of DDT levels was equivalent while HCH levels ranged from 0.01 to about 1 ng/m^3. Seawaters in the Indonesian region contained detectable levels of PCBs around 0.02 ng/L while the estuarine level at Guadalcanal was higher at <0.05 - 1.10 ng/L (see Table 4). Significant HCH levels for the Pacific Ocean were reported by Kurtz and Atlas (1990) for Samoa, 0.3 ng/L in 1987 and from 0 - 18°S, 2.5 ng/L. DDT concentrations in rivers and estuarine sediments ranged from 3.4 to 750 ng/g dry weight, with the highest level at Guadalcanal. PCBs varied from 1.1 to 200 ng/g dry weight, with the highest at Jakarta and levels at Guadalcanal relatively low. HCH levels in the same sediments ranged from 0.035 to 2.2 ng/g dry weight.

Overall, levels in the Indo-Pacific tropical regions of the Southern Hemisphere did not reflect the higher levels of contamination for PCBs, DDT and HCHs reported elsewhere. Some values were, however, comparable with those reported for Australian estuaries.

CONCLUSIONS

Occurrences of PLCs in the Southern Hemisphere are dominated by chlorohydrocarbons, particularly DDT, HCHs and PCBs. These compounds have a wide distribution throughout the Southern Hemisphere, including from low to the higher latitudes. Historical data on HCB and cyclodienes exist for Australia but few other locations. PAHs are also identified as significant contaminants of urbanised estuaries and bays. Endosulfan residues appear to be significant in regions of use although measurements are limited.

Levels of chlorohydrocarbons in Southern Hemisphere countries are elevated in (1) urbanised areas; (2) catchments with intensive agriculture; and (3) tropical - sub-tropical areas where usage for disease vector control. In these cases, the compounds accumulate in sediments and biota at levels from parts per billion (ng/g) to low parts per million or higher where usage is heavy or outfalls exist. In Australia, the data indicate that levels of several PLCs (DDT, dieldrin, heptachlor and aldrin) in water on occasions reach unacceptable levels for human health, particularly in the 1960s to 1980s.

Comparable data between continents and regions of the Southern Hemisphere are lacking or very limited. Levels and patterns of contamination appear to depend upon usage rates and/or methods of disposal in Australia, Southern Africa, South America, the Indo-Pacific and Antarctica. The most critical factor for further knowledge on the distribution and control of PLCs in the Southern Hemisphere is to obtain comparable measurements between countries and regions using selected environmental substrates from different land uses (e.g. urban, rural and remote). A wider range of PLCs should also be explored than the chlorohydrocarbons, including the PAH's and endosulfan. International environmental standards or guidelines, for levels that will allow protection of the natural environment and human health, need to be developed for PLCs in air, waters, sediments and biota.

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Table 1 Global Production of Some Key Persistent Lipophilic Contaminants

Persistent Lipophilic Contaminants	Current production (tonnes / year)	Cumulative production (tonnes)	Notes	Reference
DDT	40,000 - 50,000	2,600,000 2,800,000 - 3,000,000	· unrecorded production is believed to occur	Voldner & Li, 1995 IEM, 1995
Toxaphene	sec Notes Section	1,330,000	· recorded production ceased 1991, but unrecorded production may still occur	Voldner and Li, 1995 IEM, 1995
Hexachlorobenzene	no reliable records - see Notes Section	100,000 - 200,000	· widely produced as byproduct of manufacture of chlorinated organics including solvents and other pesticides, and in flue gases · up to 10,000 tonnes/year manufactured for fungicide use in 1980s	Voldner and Li, 1995
Pentachlorophenol	30,000	1,300,000 - 1,500,000	· commonly contaminated with HCB, PCDDs and PCDFs to 0.6%	IEM, 1995
Endosulfan	12,000	3,000,000		IEM, 1995
Chlordane	no reliable records	150,000	· most current use is in tropical region or Southern Hemisphere	IEM, 1995
Hexachlorocyclohexanes (HCHs)	>40,000	550,000	· isomeric mixture of hexachlorocyclohexanes. " isomer up to 80% · γ isomer (lindane) has insecticidal activity. · unrecorded manufacture is believed to occur	Voldner and Li, 1995 IEM, 1995
Lindane (gamma-hexachlorocyclohexane)	8,300	720,000	· most use may be as a component of HCHs (see above)	Voldner and Li, 1995 IEM, 1995
Polychlorinated biphenyls (PCBs)	no reliable records, but believed to be minimal	1,200,000	· estimated to be released to the environment. · still in service or stockpiled for disposal.	IEM, 1995 Richardson and Waid, 1982

Table 2 **Availability of Environmental Data on Persistent Hemisphere Lipophilic Contaminants and Related Compounds in the Southern**

Organic Pollutants	Significant Data	Limited to V. Limited Data	Insignificant Data	No Available Data
Aldrin	√			
Chlordane	√			
DDT	√			
Dieldrin	√			
Dioxins and Furans		√		
Endrin			√	
Heptachlor (Heptachlor Epoxide)	√			
HCB	√			
Mirex				√
PCBs	√			
Toxaphene				√
PAHs		√		
Endosulfan		√		
Atrazine		√		
HCH	√			

Table 3 Concentrations* of Persistent Lipophilic Contaminants in the Atmosphere of the Southern Hemisphere

Compound	Region	Environment	Year	Total Number	Concentration	Reference
DDT	Antarctica	Oceanic	1980-1990	47	<0.2 to 240 pg/m^3	Larsson et al, 1992 Iwata et al, 1993 Bidleman et al, 1993
DDT	Australasia	Oceanic	1989-1990	8	2.1 to 2.7 pg/m^3	Iwata et al, 1993
DDT	Australasia	River & estuarine	1989-1991	5	8.8 to 1300pg/m^3	Iwata et al, 1994
DDT	Indian Ocean	Oceanic	1980-1986	5	0.125 to 0.16 pg/m^3	Tanabe et al, 1982 Iwata et al, 1993
PCB	Antarctica	Oceanic	1980-1990	49	<0.001 to 12.3 ng/m^3	Tanabe et al, 1983 Larsson et al, 1992
PCB	Australasia	River & estuarine	1989-1991	7	2.3 to 8.0 ng/m^3	Iwata et al, 1994
PCB	Indian Ocean	Oceanic	1986	-	0.125 ng/m^3	Ballschmiter & Wittlinger, 1991
PCB	Western Pacific Ocean	Oceanic	1981	5	0.083 to 0.50 ng/m^3	Tanabe et al, 1982
HCH	Antarctica	Oceanic	1988-1990	42	0.0005 to 0.055ng/m^3	Bidleman et al, 1993 Larsson et al, 1992 Iwata et al, 1993
HCH	Australasia	Oceanic	1989-1990	2	0.075 to 0.120 ng/m^3	Iwata et al, 1993
HCH	Indian Ocean	Oceanic	1989-1990	5	0.027 to 0.120 ng/m^3	Iwata et al, 1993
HCH	Pacific Ocean	Oceanic	1981-1987	-	0.011 to 0.380 ng/m^3	Tanabe et al, 1982 Kurtz & Atlas, 1990
HCB	Antarctica	Oceanic	1990	3	40 to 78 pg/m^3	Bidleman et al, 1993
Heptachlor & Heptachlor oxide	Antarctica	Oceanic	1990	7	0.25 to 0.75 pg/m^3	Bidleman et al, 1993
Total Chlordane	Antarctica	Oceanic	1990	-	1.3 to 1.8 pg/m^3	Bidleman et al, 1993
Total Chlordane	Indian Ocean	Oceanic	1989-1990	10	0.3 to 14.0 pg/m^3	Iwata et al, 1993

* Total for all congeners and related degradation products unless otherwise noted.

Table 4 **Concentrations of Persistent Lipophilic Contaminants in Marine and Fresh Waters of the Southern Hemisphere**

Compound	Region	Environment	Year	Total Number	Concentration	Reference
DDT	Antarctica	Oceanic	1989-1990	5	0.0006 to 0.015 ng/L	Iwata et al, 1993
DDT	Australia	Fresh water estuarine	1979-1991	500	<1 to 42,900 ng/L	Garman & Sutherland, 1983
DDT	Argentina	River	1988-1989	127	<3.0 to 26	Janiot et al, 1994
DDT	Argentina	Oceanic	1980-1981	51	< detection limit to 602 ng/L	Sericano & Pucci, 1984 Colombo et al, 1990
DDT	Indonesia	River & estuarine	1990-1991	3	0.190 to0.270 ng/L	Iwata et al, 1994
DDT	Indian Ocean	Oceanic	1898-1990	5	0.0013 to 0.0043 ng/L	Iwata et al, 1993
PCB	Antarctica	Oceanic	1980-1981	10	0.035 to 0.072 ng/L	Tanabe et al, 1982
PCB	Southern Ocean	Oceanic	1989-1990	5	to 0.010 ng/L	Iwata et al, 1993
PCB	Argentina	Sea water	1986	13	21.8 ± 15 ng/L	Colombo et al, 1990
PCB	Argentina	Sea water	1989-1991	-	<4 ng/L	Philip, 1995
HCH	Antarctica	Sea water	1989-1990	8	0.47 ± 0.22 ng/L	Sericano & Pucci, 1984
HCH	Antarctica	Sea water	1980-1981	15	52 ± 38.7 ng/L	Sericano & Pucci, 1984
HCH	Argentina	Fresh water	1981	48	8 ± 13.6 to 58 ± 52.5 ng/L	Lenardon et al, 1984
HCH	Australia	Rivers	1974-1980	>411	<1 to 1100 ng/L	Cullen, 1990
HCH	Indian Ocean	Oceanic	1980-1981	4	0.3 ± 0.3 to 2.0 ± 0.9 ng/L	Sericano & Pucci, 1984
HCH	Pacific Ocean	Oceanic	1987	-	2.5 ng/L	Kurtz & Atlas, 1990
HCH	Solomon Islands	Sea water	1989-1991	6	0.063 to 5.2 ng/L	Iwata et al, 1993
HCH	Uraguay	River	1988	64	0.9 to 10 ng/L	Janiot et al, 1994
Dieldrin	Argentina	Rivers	1988-1989	127	<2.6 to 7.2 ng/L	Janiot et al, 1994
Dieldrin	Australia	Rivers	1964-1989	ca 600	<1 to 1100 ng/L	Cullen, 1990
Heptachlor & heptachlor epoxide	Argentina	Rivers	1981-1986	-	<detection limit to 30 ng/L	Colombo et al, 1990 Lenardon et al, 1984
Heptachlor & heptachlor epoxide	Australia	Rivers	1982	-	20 ng/L	Cullen, 1990
Heptachlor & heptachlor epoxide	Uruguay	Rivers	1988	284	0.8 ± 0.1 to 1.3 ± 0.3 ng/L	Janiot et al, 1994
Chlordane	Indian Ocean	Oceanic	1989-1990	10	2.4 to 15.0 pg/L	Iwata et al, 1993
Aldrin	Argentina	Sea water	1980-1981	45	<detection limit to 853.2 ng/L	Sericano & Pucci, 1984
Aldrin	Argentina	Rivers	19088-1989	127	<1.0 to 6.3 ng/L	Janiot et al, 1994

Table 5 Concentrations* of Persistent Lipophilic Contaminants in Aquatic Sediments in the Southern Hemisphere

Compound	Region	Environment	Year	Total Number	Concentration	Reference
DDT	Australia	Fresh water agricultural	1972-1991	-	0.002 to 11.3 μg/g	Cullen, 1990
DDT	Argentina	Marine	1986	17	0.0061 ± 0.007 μg/gdw	Colombo et al, 1990
DDT	Brazil	Marine	1988	-	0.005 to 0.08 μg/gdw	Japenga et al 1988
DDT	Indonesia	Rivers	1990-1991	4	0.003 to 0.04 μg/gdw	Iwata et al, 1993
DDT	Papua New Guinea	Rivers	1990-1991	3	0.005 to 0.13 μg/gdw	Iwata et al, 1991
DDT	Zimbabwe	Lake	1994	8	5.6 to 118 μg/g	Zaranyika et al, 1994
PCB	Antarctica	Marine	1989-1993	41	2.8 to 4,300 ng/gdw	Kennicutt et al, 1995
PCB	Argentina	Marine	1986	16	15.7 ±19.2 ng/gdw	Colombo et al, 1990
PCB	Australia	Rivers	1976-1998	17>120	0.49 to 790 ng/gdw	Shaw & Connell, 1980
PCB	Indonesia	Rivers	1989-1994	4	5.9 to 220 ng/gdw	Iwata et al. 1994
PCB	Solomon Islands	Rivers	1989-1991	2	1.1 to 5.0 ng/gdw	Iwata et al, 1994
PCB	Brazil	Coastal	1988	-	ca 4 to 25 ng/g	Japenga et al, 1988
HCH	Argentina	Lake & River	1980-1981	-	0.2 to 1,866 ng/g	Lenardon et al, 1984
HCH	Australia	Rivers	1979-1991	-	0.18 to 17 ng/gdw	Cullen, 1990 Iwata et al, 1994
HCH	Indonesia	Rivers	1989-1991	4	0.035 to 0.09 gdw	Iwata et al, 1994
HCH	Solomon Islands	Rivers	1989-1991	2	<0.33 to 2.2 ng/gdw	Iwata et al, 1994
HCH	South Africa	Rivers	1989-1991	6	<0.2 ng/gdw	Roux et al, 1994
Dieldrin	Australia	Rivers	1973-1985	-	0.08 to 410 ng/g	Cullen, 1990 Connell, 1986
Dieldrin	New Zealand	Marine	1988	5	0.3 to 0.5 ng/g	Hamilton, 1988
Dieldrin	Zimbabwe	Lake	1994	7	2270 to 22,800 ng/g	Zaranyika et al, 1994
HCB	Australia	Marine	1990-1993	6	<0.6 to 871 ng/g	EPA, 1994 Mortimer & Connell, 1995
HCB	New Zealand	Marine	1988	-	<0.01 ng/g	Hamilton, 1988
Heptachlor & heptachlor epoxide	Argentina	River	1986	17	<detection limit to 15.6 ng/g	Colombo et al, 1990
Chlordane	Argentina	River	1986	17	3.4 mean ng/g	Colombo et al, 1990
Chlordane	Australia	River	1979	-	1.5 mean ng/g	Cullen, 1990
Aldrin	New Zealand	Marine	1988	5	<detection limit	Hamilton, 1988
Aldrin	Zimbabwe	Lake	1994	4	0.017 to 4.10μg/g	Zaranyika et al, 1994

* in wet weight terms unless dw is used to indicate dry weight

Table 6 Concentrations of PAHs in Australia and Antarctica

Substrate	Region	Environment	Year	Total Number	Concentration	Reference
Aquatic Invertebrates	Great Barrier Reef	Natural	1980-1983	>21	<0.025 to 6.72 ng/g	Smith et al, 1984 Smith et al, 1987
Aquatic Invertebrates	Port Philip Bay	Urban	1991	-	0.7 to 18.0 ng/gdw	Nicholson et al, 1994
Fish	Arthur Harbour & McMurdo Sound	Antarctic	1993	12	< detection limit to 656 ng/g	Kennicutt et al, 1995
Fish	Port Phillip Bay	Urban	1990	-	<detection limit to 55.7 ng/*gdw*	Nicholson et al, 1994
Sediments	Arthur Harbour & McMurdo Sound	Antarctic	1990-1991	-	<200 to 6,267 ng/g	Kennicutt et al, 1995
Sediments	Australia	Urban	19811987	-	<0.5 to 16,110 ng/gdw	Nicholson et al, 1994 Kayal & Connell, 1989
Water	Australia	Urban	1984-1987	-	1 to 2,400 ng/L	Nicholson et al, 1994 Kayal & Connell, 1989
Soils	Australia	Urban	1987	-	300 to 3347 ng/g	Yang, 1988

Table 7 **Concentrations of Endosulfan in Waters and Sediments**

Substrate	Region	Environment	Year	Total Number	Concentration	Reference
Water	Australia	Rivers	1982-1985	-	0.05 to 2.12 μg/L	Cullen, 1990
Water	Australia	Irrigation Area	1991-1995	>600	0.01 median to 0.125 median μg/L	Department of Land & Water Conservation, 1995
Sediments	Australia	Irrigation Area	1994-1995	-	3 to 11 ng/g	Department of Land & Water Conservation, 1995
Sediments	Zimbabwe	Rivers	1994	7	2.2 to 167.8 μg/g	Zaranyika et al, 1994

Table 8 Concentrations of Persistent Lipophilic Contaminants in Aquatic Biota

Compound	Region	Environment	Year	Total Number	Concentration	Reference
DDT	Australia	Invertebrates	1969-1994	-	<0.001 to 4.4 µg/g	Cullen, 1990
DDT	Australia	Fish	1969-1994	-	< detection limit to 40.3 µg/g	Cullen, 1990
DDT	South Africa	Fish	1992	13	<0.1 to 181.0 µg/g	Roux et al, 1994
PCB	Antarctica - NF Murdo	Invertebrates	1989-1993	8	5.1 to 430 ng/g	Kennicutt et al, 1995
PCB	Antarctica	Fish	1981	-	0.08 to 0.77 ng/g	Subramanian et al, 1983
PCB	Australia	Invertebrates	1970-1994	-	< detection limit to 930 ng/g	Phillips et al, 1992 Shaw & Connell, 1980
PCB	Australia	Fish	1970-1994	-	< detection limit to 5,000 ng/g	Shaw & Connell, 1980
PCB	Argentina	Fish / Bivalves	1986	7	8,000 ± 4,800 ng/g	Colombo et al, 1990
PCB	Eastern South Pacific	Fish	1977-1978	31	0.06 to 0.33 ng/g	Tanabe et al, 1980
PCB	Papua New Guinea	Fish	-	9	0.8 to 11.0 ng/g	Kannan et al, 1994
PCB	South Africa	Fish	-	31	<1 to 41 ng/g	Grobler, 1994
HCH	Argentina	Various Species	1986	7	600 ± 500 ng/g	Colombo et al, 1990
HCH	Australia	Fish		215	0.06 to 130 ng/g	Miskiewicz & Gibbs, 1994 Nicholson et al, 1994 Cullen, 1990 Olafson, 1978
HCH	Australia	Invertebrates	1969-1976	104	0.01 to 2.0 ng/g	Olafson, 1978 Thomson & Davie, 1974
HCH	Papua New Guinea	Fish	-	9	0.3 to 1.6 ng/g	Kannan et al, 1994
HCH	Papua New Guinea	Invertebrates	-	4	0.48 to 0.89 ng/g	Kannan et al, 1994
HCH	Solomon Island	Fish	-	10	0.23 to 1.9 ng/g	Kannan et al, 1994
HCH	South Africa	Fish	1992	-	<0.1 ng/g	Roux et al, 1994
Dieldrin	Australia	Fish	1979-1994	570	0.09 to 6,000 ng/g	Cullen, 1990 Olafson, 1979 Nicholson et al, 1994 Cullen & Connell, 1992 Mortimer and Connell, 1995
Dieldrin	Papua New Guinea	Various	1994	13	0.10 to 2.5 ng/g	Kannan et al, 1994
Dieldrin	Solomon Islands	Fish	1994	10	0.10 to 1.6 ng/g	Kannan et al, 1994
HCB	Australia	Invertebrates	1974-1993	>20	< detection limit to 0.002 ng/g	Miskiewicz & Gibbs, 1994 Cullen, 1990

Compound	Region	Environment	Year	Total Number	Concentration	Reference
HCB	Australia	Fish	1973-1994	860	0.001 to 3.0 ng/g	Miskiewicz & Gibbs, 1994 Cullen, 1990 Mortimer & Connell, 1995
Heptachlor & heptachlor epoxide	Argentina	Various	1986	17	0.7 to 2.0 µg/g	Colombo et al, 1990
Heptachlor & heptachlor epoxide	Australia	Invertebrates	1977	-	< detection limit to 0.03 ng/kg	Cullen, 1990
Heptachlor & heptachlor epoxide	Australia	Fish	1979-1994	>660	< detection limit to 4.8 ng/g	Cullen, 1990
Heptachlor & heptachlor epoxide	Papua New Guinea	Invertebrates	1994	-	< detection limit to 0.15 ng/g	Kannan et al, 1994
Heptachlor & heptachlor epoxide	South Atlantic Ocean	Fish	1988	-	< detection limit to 0.07 ng/g	DeBoer & Wester, 1991
Heptachlor & heptachlor epoxide	South Atlantic Ocean	Squid	1988	-	< detection limit to 0.02 ng/g	DeBoer & Wester, 1991
Chlordane	Argentina	Various	1986	-	2.9 mean ng/g	Colombo et al, 1990
Chlordane	Australia	Invertebrates	1977-1993	-	< detection limit to 0.5 µg/g	Cullen, 1990 Miskiewicz & Gibbs, 1994
Chlordane	Australia	Fish	1988-1993	940	< detection limit to 1.7 µg/g	Miskiewicz & Gibbs, 1994 Mortimer & Connell, 1995
Chlordane	South Atlantic Ocean	Fish	1988	-	0.09 to 0.1 ng/g	DeBoer & Wester, 1991
Aldrin	Australia	Various	1969-1992	-	0.001 to 33 µg/g	Thomson & Davie, 1974 FPMEC, 1992
Aldrin	Chile	Invertebrates	1985	-	4.0 to 33 ng/g	FPMEC, 1992
Aldrin	Nigeria	Invertebrates & Fish	1987	7	< detection limit to 54.6 ng/g	FPMEC, 1992
Aldrin	Papua New Guinea	Various	1994	13	<0.1 to 2.1 ng/g	Kannan et al, 1994
Endrin	Australia	Invertebrates	1977	-	<1 to 40 ng/g	Cullen, 1990

Table 9 **Concentrations of Persistent Lipophilic Contaminants in Vegetation in the Southern Hemisphere**

Compound	Region	Substrate	Year	Total Number	Concentration	Reference
DDT	Antarctica	Richens & Mosses	1985-1988	23	0.5 (mean)and 0.4 (mean) ng/gdw	Calamari et al, 1991
DDT	Bolivia	Lichens & Mosses	1985-1988	9	2 (mean) ng/gdw	Calamari et al, 1991
DDT	Southern Africa	Mango	1985-1988	8	< detection limit to 50 ng/gdw	Calamari et al, 1991
DDT	Southern Indian Ocean	Mango	1991	16	<0.1 to 2140 ng/gdw	Tremolada et al, 1993
HCH	Antarctica	Lichens & Mosses	1985-1988	24	0.21 (mean)and 1.03(mean)ng/gdw	Calamari et al, 1991
HCH	Bolivia	Lichens & Mosses	1985-1988	9	2 ng/gdw	Calamari et al, 1991
HCH	Indian Ocean	Mango	1991	-	0.3 ng/gdw	Calamari et al, 1991
HCH	Indonesia	Mango	1991	-	0.04 to 0.24 ng/gdw	Calamari et al, 1991
HCH	Southern Africa	Mango	1985-1988	21	0.4 to 3.45 ng/gdw	Calamari et al, 1991

Table 10 Chlorohydrocarbons in Marine Mammals from Southern Hemisphere (ranges in µg/g, blubber)*

Locations	Chlorohydrocarbon					
	HCB	**DDT**	**PCBs**	**Heptachlor (Epoxide)**	**Chlordane**	**HCH**
South Atlantic						
South African Waters	0.01-0.27		LOD-15.51			
Australasia						
Marine Mammals	0.001-0.41	0.01-28.4	<0.05-1.4			
Victorian (Fur Seals)	LOD-1.0		0.05-3.87	0.002-0.17	LOD-0.047	0.01-0.14
Antarctica		0.016-2.4	0.01-0.03**			

* from Bacon et al, 1992; de Kock et al, 1994; O'Shea and Brownwell, 1994; Smillie and Waid, 1992. **minke whales

Table 11 **Australian Guidelines for the Protection of the Environment and Human Consumers (ANZECC, 1992) of Fish and other Aquatic Organisms**

Parameter	**Water Concentration***	**Water Concentration****
	(ng/L)	**(ng/L)**
Aldrin	10	0.08
Chlordane	4	0.5
DDT	1	0.03
Dieldrin	2	0.08
Heptachlor	10	0.3
Total PAH	3000	30
2, 3, 7, 8 - tetrachlorodibenzodioxin (TCDD)	<to 10	0.00001
HCB	-	0.7

*protection of the natural system

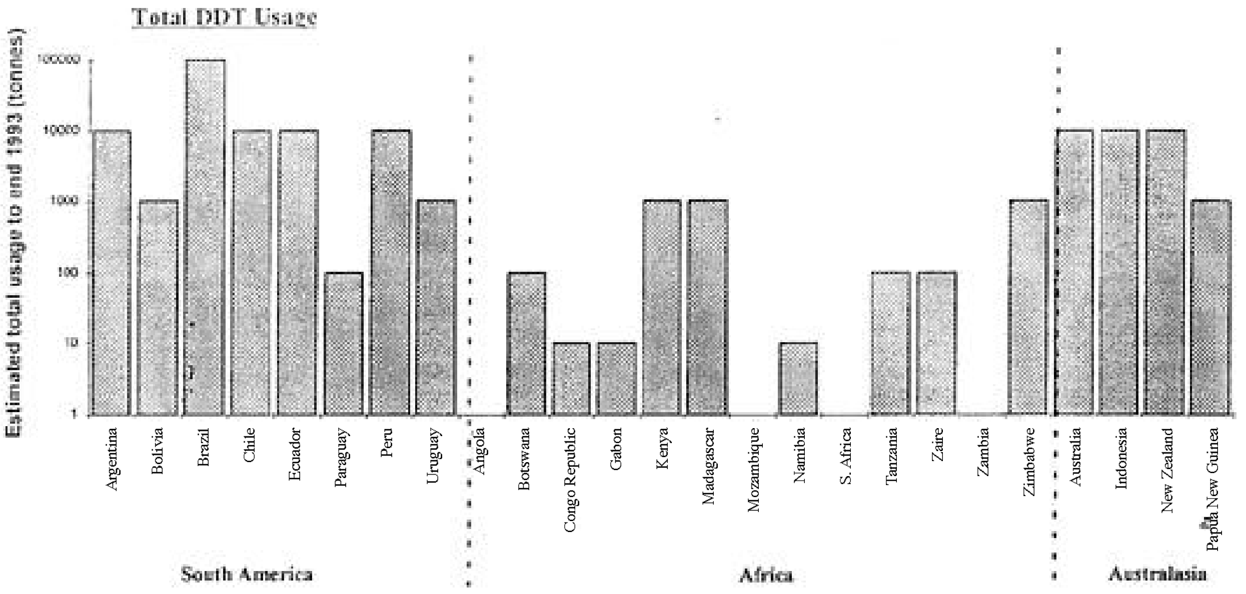
**protection of human consumers of fish and other aquatic organisms

FIGURE CAPTIONS

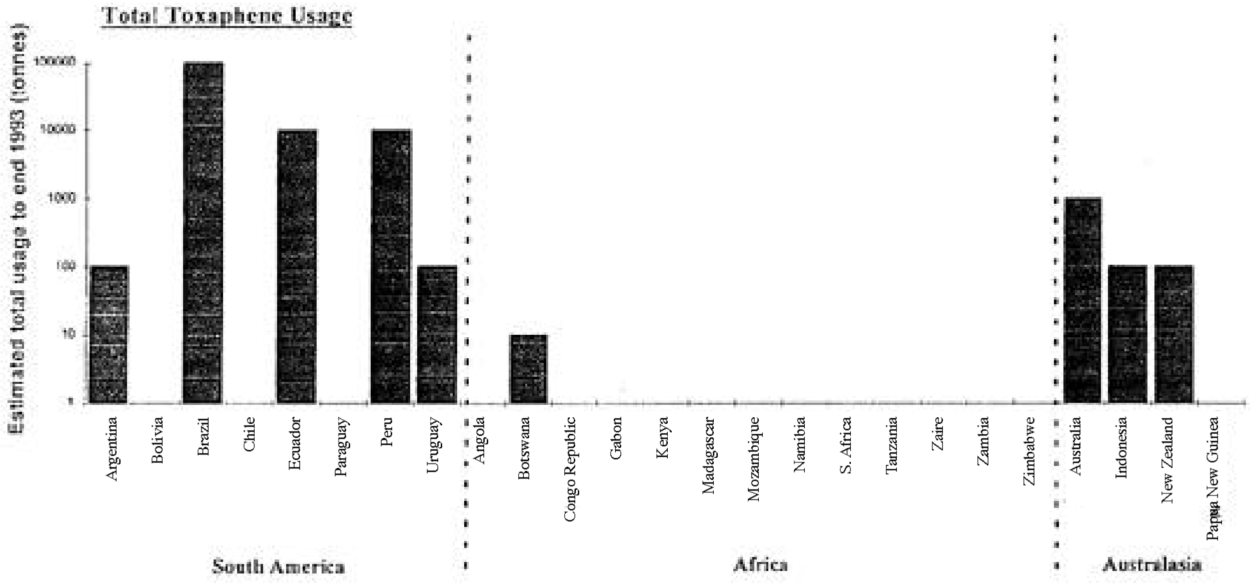
FIGURE 1. Estimations of the documented usage of DDT, toxaphene and lindane up to the end of 1993 in various countries of the Southern Hemisphere.

FIGURE 2. Comaprisons of HCB in plants in the Northern and Southern Hemispheres:
(1) Iceland/Antarctic Penninsula; (2) Spitsbergen/Tierra del Fuego; (3) Scandinavia/Capetown;
(4) New Dehli/Amazonas; respectively.

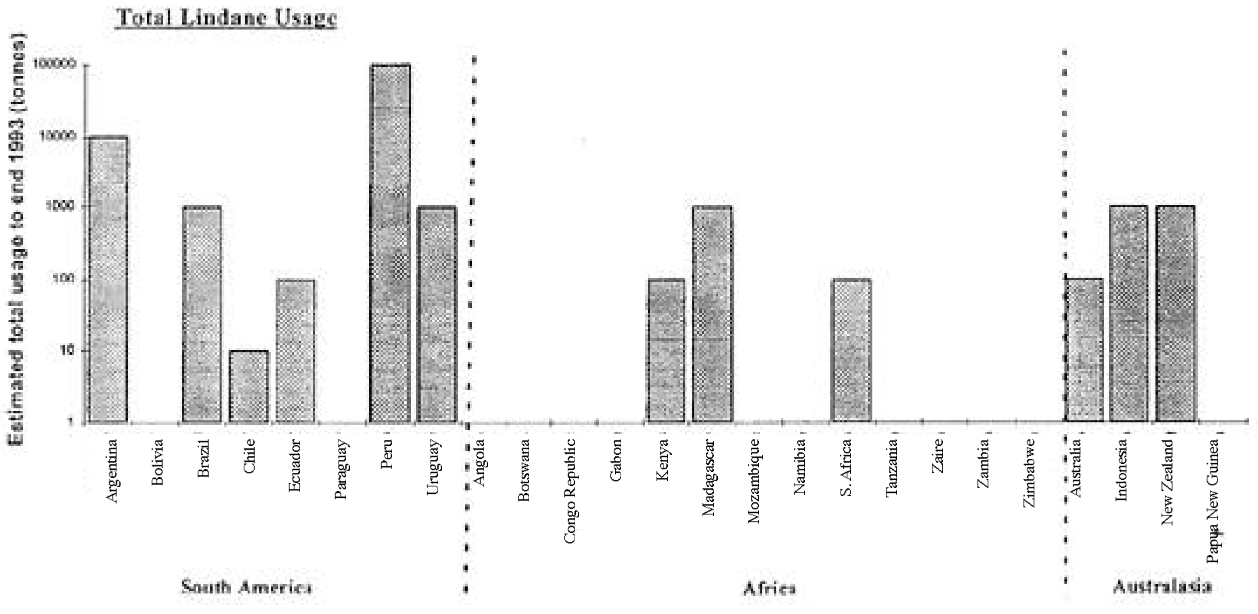
FIGURE 3. Comparisons of DDT in plant and animal biomass in the Northern and Southern Hemispheres: (1) Iceland/Antarctic Penninsula; (2) Spitsbergen/Tierra del Fuego;
(3) Scandinavia/Capetown; (4) New Dehli/Amazonas; (5) Northern Fur Seal/Antarctic Fur Seal;
(6) California Sea Lion/Australian Sea Lion; respectively.



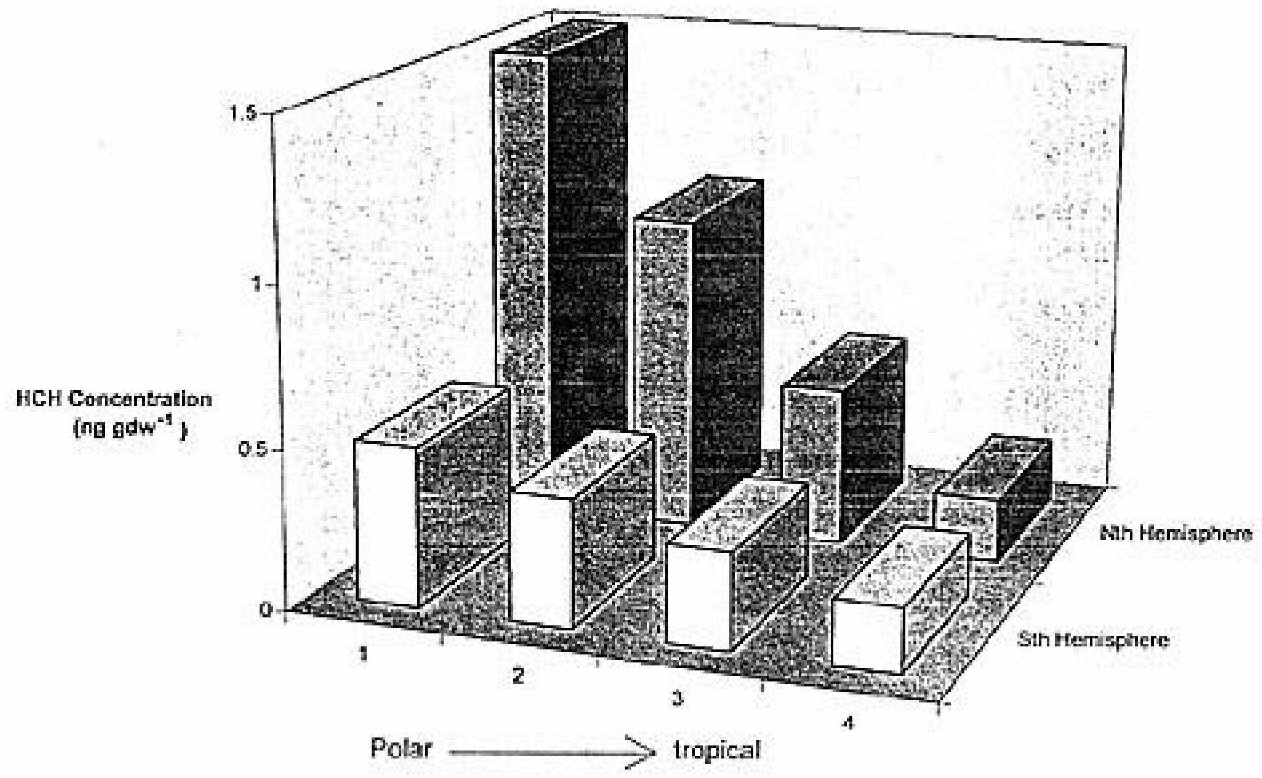
Total DDT Usage



Total Toxaphene Usage



Total Lindane Usage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0.5
0
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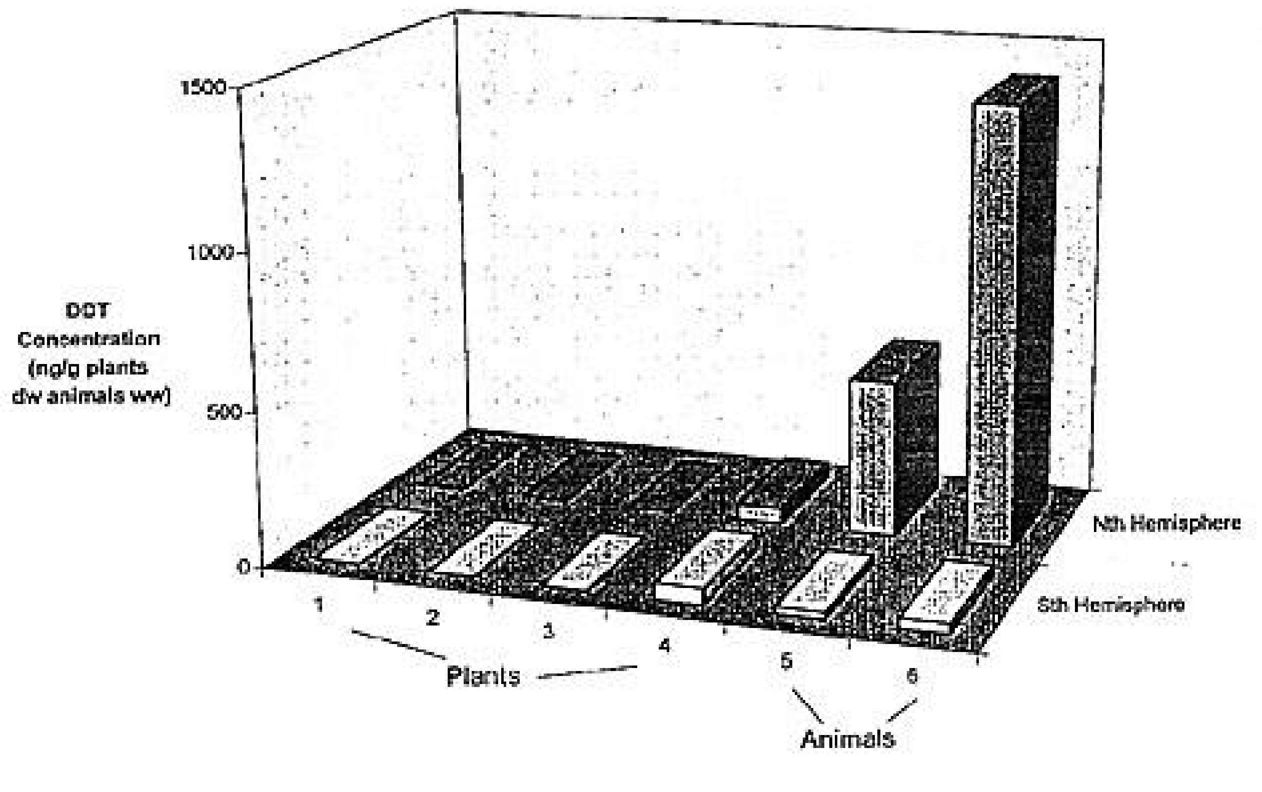
1
2
3
4
Polar → tropical
Nth Hemisphere
Sth Hemisphere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1000
500
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DDT Concentration (ng/g plants dw animals ww)
1
2
3
4
5
6
Plants
Animals
Nth Hemisphere
Sth Hemisphere