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MONITORING PCB IN WATER AND WILDLIFE

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INTRODUCTION

Although polychlorinated biphenyls (PCB) have been manufactured for various purposes for the past forty years, it was not until 1966 that Jensen identified them in a variety of environmental samples, using the gas chromatographic technique employed since 1962 for the detection and measurement of the persistent organochlorine pesticides such as DDT (and its metabolites) and dieldrin. Confirmation of the identity of the PCB residues was made by mass spectrometry, which at the same time indicated the presence of a larger number of polychlorinated biphenyls than was suggested by the number of gas chromatographic peaks.

In the analysis of wildlife samples for organochlorine pesticides since 1962, several workers had recorded the presence of a number of unidentifiable GLC peaks. Jensen's discovery of the presence of PCB residues, while assisting in the determination of a further group of detectable contaminants, made it evident that some of the earlier analytical results reported in the literature, particularly for pp'-DDT and pp'-DDD, were probably erroneous. Subsequently techniques have been developed to enable a reasonable degree of separation of PCB from many organochlorine pesticides to be achieved before GLC analysis, but the PCB residues must still be estimated as a group at present.

Polychlorinated biphenyls can be used for a wide variety of purposes, and the mixtures of isomers produced by the various manufacturers may range from those containing about 20% by weight of chlorine, averaging about one chlorine atom per molecule, to some containing about 70% of chlorine, averaging almost nine chlorine atoms per molecule. A total of 209 chlorinated biphenyls, containing from one to ten chlorine atoms, is theoretically possible, and it has been shown (Simons and Welti, 1971) that one particular 54% chlorinated mixture contains at least fifty different isomers. Few of these have been prepared individually, and consequently for routine analysis of environmental

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samples the commercially-available mixtures must be used as reference standards. Some degradation of the lesser-chlorinated members of the series probably occurs in the environment, and in consequence the pattern of GLC peaks obtained from wildlife samples differs from that of the commercial mixtures. The estimation of total PCB content and toxicity of the wildlife residues are therefore only approximate at the present time.

In view of the persistence of the higher polychlorinated biphenyls, their presence at all environmental levels, their potential interference in the analysis for organochlorine pesticides, and their possible toxicity to various forms of life, considerable attention has been given in recent years to the problem of their world-wide distribution. Most studies have involved fish and birds, but in view of the possibility that global monitoring programmes for pollutants such as organochlorines may be established in the near future some consideration must be given to the types of environmental samples most suitable for the purpose of monitoring.

The Organisation for Economic Co-operation and Development(OECD) has for several years sponsored voluntary international studies of the problem of sampling and analysing wildlife specimens for organochlorine residues, and this paper summarizes the results of the first six years of investigation, and indicates the difficulties involved both in the analysis of the samples and in the selection and acquisition of the necessary sample material. It has been possible to compare the efficiency of analysis in different countries, and to assess the importance of analytical errors as compared with the variations between individuals in populations of certain species. The occurrence of PCB concentrations in environmental media as opposed to living organisms is also discussed, media samples sometimes being suggested in preference to wildlife samples for monitoring purposes.

ANALYTICAL METHODS

PCBs are extracted and analysed by the same techniques as are employed for organochlorine pesticides, and appear to be recovered from water and tissue samples with the same efficiency, but must be separated from the majority of pesticides before GLC analysis to avoid interference. Separation is usually made using silica column chromatography,

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the PCB compounds being eluted with p,p'-DDE (Holden and Marsden, 1969), although Armour and Burke (1970) achieved a degree of separation of the PCBs from DDE with a more active type of silica. Several methods have been proposed for the determination of the total PCB content from the gas chromatographic trace, but a recent OECD study (Holden, in preparation) has shown that a considerable measure of agreement can be obtained among analysts using different methods of estimation.

Peak height is usually measured although peak area, measured by electronic integration or mechanical devices, is sometimes used; 4 to 6 GLC peaks are commonly involved. The estimation of PCB concentration is influenced to some extent by the choice of a suitable reference standard, which is usually arbitrary in view of the difference in proportions of the various PCB peaks, as between environmental samples and commercial products. Nevertheless, in the recent OECD study, eight analysts using different methods of estimation but similar 60% chlorinated reference mixtures obtained results on a cormorant sample which showed a coefficient of variation of ±14%, a value no greater than was obtained for some individual pesticides in another exchange sample used in the same OECD study. An alternative method of assessment, not yet widely used, is the complete chlorination of all PCB residues found to the deca-chloro compound, giving a single GLC peak which is compared with the same peak produced from any PCB formulation, or a deca-chloro-biphenyl standard.

Where low-level concentrations are being determined, as in water or plankton samples, great care is necessary to avoid contamination from laboratory or other sources which may give GLC peaks in positions similar to those from the samples. Such contamination, insignificant in the analysis of samples containing high concentrations of PCBs, can be derived from plastics (particularly PVC), oil used in air compressors, human skin (if not adequately washed beforehand), internal seals of metal containers, and in the solvents or adsorbents used in analysis. All solvents must be purified by distillation, and all adsorbents or drying media (e.g. alumina, silica, sodium sulphate) must be calcined or solvent-washed before use. Blank runs through the complete analytical procedure must be made frequently to check for possible contamination.

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PCB LEVELS IN THE ENVIRONMENT

(a) Air and Rain No reference has been found in the literature to concentrations of PCB in gaseous form in air, and it is quite possible that atmospheric PCB is associated with particulate matter (dust) or water droplets. In the sampling of air, such forms would be removed by filters and analysed as particulate matter. Risebrough et al (1968)[a] found 1 to 64 ppb of organochlorines in dust from air over Barbados, but did not positively identify PCB. Analysis of airborne dust off the California coast did not reveal the presence of PCB, and the deduction was made that PCB do not adsorb to particulate matter.

In the sampling and analyses of atmospheric precipitation for organochlorines, only the common pesticides ∝- and Y-BHC, dieldrin, pp' DDT and its metabolites pp'-TDE and pp'-DDE have been reported in detail. Wheatley and Hardman (1965) and Tennant and Tatton (1968) found these residues in rain in the United Kingdom, but the latter also noted the presence of other residues believed to be PCB, without quantifying them. Their existence was confirmed in further rain samples collected in London (Annual Report of the Laboratory of the Government Chemist, 1970), with an approximate (TIC) estimate of their concentration as 50-100ng/l.

Rain samples have been collected and analysed from four different sites in Scotland during 1972, and preliminary results indicate that PCB levels are in the range 20-40ng/l, with total DDT levels of 5-20ng/l. These samples are taken in all-glass equipment, protected from birds, the aerial debris (dust, pollen, etc.) being retained separately on pre-washed glass wool filters which are also analysed. Several hundred millilitres of rain must be collected, the sampling periods being irregular according to the prevailing weather conditions. The concentrations of organochlorines found in the samples are nevertheless much higher than in river and stream waters in Scotland. Furthermore, there is so far no evidence that the residues are transported from industrial areas of Scotland by prevailing winds and it seems likely that the contamination is of more distant origin, or perhaps reflects a general level of atmospheric contamination. In this form of sampling, however, it is impossible to exclude the possibility of transient local contamination, whether from

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the excreta of flying birds, from insects, or passive transport, and such events should not be ignored.

(b) Fresh Waters A few references to PCB concentrations in rivers have appeared in the literature, although these generally refer to local contamination. In the Milwaukee River, U.S.A., 20-200ppt of Aroclor 1260 and 80-2070ppb of Aroclor 1242 were detected (Veith and Lee, 1971). In Lake Biwa, Japan, 100-1000ppt of PCB were found (Iseno, 1971). Ahling & Jensen (1970) found 0.33 and 0.50ppt in natural waters in Sweden, but particulate material contained 1350ppt. The sediments in Ontario (Canada) rivers have been found to contain up to 0.6p.p.m. (Berg et al. 1972), and in several U.S. rivers up to 3.2ppm (Yates et al. 1972). The latter also found 0.1-4ppb in unfiltered river waters from the United States. The Michigan Water Resources Commission has reported 10-2900ppt in 30 tributary streams to the Great Lakes (Anon, 1972).

Analyses of Scottish streams and rivers for organochlorines in 1971 and 1972 have shown that, even in streams with no evidence of industrial or gross sewage pollution, the PCB concentrations are in the range 2-20ppt in unfiltered samples. The concentrations of organochlorine pesticides found were 0.1-5.1ppt dieldrin, 0.3-5.3ppt DDE, 0.3-6.4ppt TDE and 0.2-5.7ppt DDT, excluding badly-polluted rivers. These residues, with the possible exception of dieldrin (used for about ten years in sheep dips throughout Scotland until 1966), are believed to result from atmospheric, rather than terrestrial contamination. The PCB estimations were made on the basis of fewer peaks than is customary for tissue samples, and further examination is likely to reduce the values quoted above.

(c) Sea Water Analysis of a sea-water sample from the Firth of Clyde, West Scotland, an area which receives about one million tons of sewage sludge per annum, showed a concentration of 6ppt. Previous investigations (Holden, 1970) had shown that about one ton of PCBs were probably contained in the annual discharge of sludge but during 1972 the source from which the PCB entered the sewer was removed. Sea-water samples from the Firth of Tay, East Scotland, contained 5-20ppt, the higher values

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being in the vicinity of the city of Dundee. Much of this may have been in particulate matter.

(d) Freshwater Fish The levels of PCB in freshwater fish have been reported from only a few areas, partly due to the fact that pesticide concentrations in rivers and streams in agricultural areas are often greatly in excess of PCB levels, but also, as in Scotland, because terrestrial sources of direct contamination are often non-existent. The PCB problem has so frequently been related to the marine environment that their presence in fresh waters may have been overlooked, yet discharges of industrial wastes or crude sewage to rivers would be expected to result in significant PCB accumulation in the biomass. Possibly the fact that such rivers, if heavily polluted, may contain no fish has produced this situation, as fish are commonly used as the monitoring species for such pollutants.

Yet fish, like many other aquatic species, can concentrate PCB by at least three orders of magnitude, and it would be surprising if PCB residues were not detectable in the fish of the more polluted rivers and lakes. Zitko and Choi (1971) reported a concentration of 14.6ppm in a coho salmon (Oncorhynchus kisutch) from Lake Michigan. Other fish from Lake Michigan analysed by Veith and Lee (1970) contained 15-25ppm. Fish from the Great Miami River (Kroner, 1971) had up to 150ppm, the PCB being discharged by paper mills. Zitko (1971) found 0.36-1.01ppm in American eel (Anguilla rostrata) from New Brunswick (Canada) rivers and, as there was no evidence of industrial or sewage pollution in some of these rivers, Zitko considered atmospheric fallout to be a possible source.

(e) Freshwater Invertebrates Invertebrates are less often studied than fish, but Södergren et al (1972) used the amphipod Gammarus pulex as an indicator organism for both DDT and PCB in streams in southern Sweden. There was evidence of a seasonal variation, with higher residue levels in August than in April, the PCB concentration being 0.002-0.011ppm. A number of other invertebrates were also examined, but PCB concentrations never exceeded 0.020ppm, total DDT being up to 0.046ppm.

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(f) Marine Fish and Shellfish. Zitko and Choi (1971) summarized the analytical data reported for marine fish, the concentrations in the presumably unpolluted areas being less than 0.1ppm. In areas known to be polluted, such as the California coast, the Baltic and the Bay of Fundy, values up to 1.0ppm have been found. In a heavily polluted area such as Escambia Bay, Florida, concentrations from 4.5 to 20ppm were detected. Tissues containing a high proportion of lipids were more heavily contaminated

In a survey of the organochlorine content of commercial marine fish species from waters around the United Kingdom, (Portmann and Holden, unpublished), PCB concentrations in muscle tissue ranged from less than 0.1ppm in fish such as cod (Gadus morhua) up to 1.5ppm in plaice (Pleuronectes platessa) and mackerel (Scomber scombrus) in the polluted waters of the Firth of Clyde. Fish liver reflected contamination of the environment even more markedly, with concentrations in cod liver ranging from 0.4 to 43ppm. Expressed in terms of extractable lipid, PCB levels may range from 1ppm in unpolluted to over 300ppm in polluted areas.

The shellfish most commonly used for pollution studies have been molluscs such as oysters and mussels. However, these species seem to be able to rid themselves of contaminants such as pesticides relatively quickly, and the concentrations found may not always reflect the external conditions at the time of sampling. Nevertheless, persistent pollution in estuaries will give rise to abnormally high residue levels in mussels as found in surveys made in Scotland, using Mytilus edulis. Specimens in the Firth of Clyde contained up to 3.0ppm, while in clean waters the concentrations of 0.1-0.2ppm were more usual. The overall range, however, is not very large.

(g) Marine Plankton Marine zooplankton, with a significant lipid content, might be expected to reflect PCB levels in the surrounding aqueous medium, but two major difficulties arise in their use for monitoring. Zooplankton samples usually vary in species composition, and this may result in a between-sample variation in PCB content by virtue of the different lipid contents of the various species. Analyses based on lipid content might, however, reduce the influence of species composition. A more serious problem arises from the possibility of collecting in the plankton net

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such extraneous material as/from ships, and tar or oil, which are found almost everywhere on the ocean surface. Nets used for plankton should be closed when entering or leaving the water surface. As oil is an excellent solvent for PCB, even a small amount may produce a significant enhancement of PCB concentrations in plankton samples. Paint, hydraulic fluid or lubricating oil from ships could also be sources of PCB.

Despite these potential errors, analyses of mixed zooplankton samples in the eastern Atlantic and Firth of Clyde have shown a consistent pattern, the latter containing higher concentrations, as expected from the local PCB contamination. The samples from the north-east Atlantic contained 0.01-0.11ppm wet weight (0.1 - 4.2ppm in lipid), while samples from the Firth of Clyde, including some unpolluted areas, contained 0.04 - 2.20ppm wet weight (1.1 - 20.0ppm in lipid). Extremely high PCB concentrations, expressed in terms of extractable lipid, were obtained from plankton (more correctly seston) samples in the Bristol Channel, S.W. England, where the sediment is continually disturbed by tidal movements. The area receives a considerable amount of industrial waste, and PCB values of up to 7000ppm in lipid were calculated for the seston. Such a situation would be unlikely in the open ocean. Recent analyses of zooplankton from the Clyde suggest that species composition may have little influence on the PCB levels in zooplankton samples.

(h) Birds. Both terrestrial and aquatic species of birds may accumulate high PCB concentrations, but the piscivorous species, particularly in the marine environment, generally contain most. Ridgebrough et al (1968) recorded the results of analyses of both DDT group and PCB residues from a wide range of avian species in North America. Some species contained less than 0.01ppm in muscle tissue, but values between 0.1 and 1.0ppm were common, and in species feeding on fish in polluted areas concentrations between 10 and 100ppm were common. Zitko and Choi (1971) summarised the analyses of birds from a number of literature references, and in a few instances, such as in the Stockholm Archipelago, values between 100 and 10,000ppm/PCB were found. Such concentrations would seem to be potentially, if not actually, toxic to the birds. The eggs of several species in contaminated areas have also been found to contain high levels of PCB, sometimes 10 - 100ppm.

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The range of PCB residues in birds from various locations is thus extremely wide, from 0.01 to 10,000ppm, and much larger than is found in fish, for example. In this respect, birds would appear to be most appropriate organisms for monitoring the distribution of PCB in the environment, although other considerations must qualify this judgement, as discussed later.

(i) Marine Mammals Holden, (1972, and 1973 in press) has described the analysis of seal and porpoise fat (blubber) for organochlorine residues, and the variation in PCB concentrations found in seals from different parts of the world. Concentrations in extractable lipid range from 1ppm in the Arctic to 250ppm on the west coast of the United Kingdom, but in starving specimens, which have metabolised most of their fat reserves, up to 2800ppm has been found. The increase in concentrations in lipid, as the result of starvation stress and reduction of body fat reserves, is a complicating factor in the use of residue concentrations in organisms for assessing the extent of local environmental contamination.

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The above summary has indicated the range of concentrations of PCB to be found in the environment, but before any selection of species appropriate for monitoring is made several aspects of the problem of environmental contamination must be considered. The contaminant in question may enter an organism from the external medium, such as air or water, or from sediments in the case of an aquatic filter-feeder, and thus the media might be appropriate for sampling and analysis. However, contamination of water or air might fluctuate appreciably with time, and organisms, in which the fluctuations would be reduced, could reflect the general situation more effectively, while at the same time providing higher concentrations for easier determination. As uptake from food is an alternative, and often the only, source of contamination in most species, the concentration in the external medium may not be directly relevant.

Species of which the individuals move over considerable distances, either for feeding or on migration, may give residue information which is difficult to interpret, as the residues may not have been ingested in the area in which the specimens were

obtained. Thus adult migratory birds are not appropriate monitoring organisms. For the same reason, marine fish, which may move from estuarine to oceanic waters, could also be unsuitable. Freshwater fish which remain in a lake over a complete life-span, or invertebrates, which move over relatively short distances, can on the other hand provide information relevant only to their local environment.

A further important consideration in the choice of species for monitoring is that sufficient individuals must be available for sampling at the required time, without having a significant influence on the total population. As residue levels often increase with age, and may also differ between the sexes, the specimens may have to be selected both for age and sex, thus increasing the problem of sampling. Furthermore, there is always a natural and sometimes considerable variation among individuals within a population, even whom of one sex and age. In consequence, to obtain a reasonably accurate estimate of the mean level of contamination in any one population, a large number of individuals may be required, creating problems both in sampling and analysis.

At this point, it is worth considering the purpose for which a monitoring programme may be designed. Initially it is intended that the level of contamination in several areas will be determined, so that the more heavily contaminated areas can be identified, and the sources of pollution controlled. Yet, unless these are already known or suspected, and sampling areas chosen accordingly, a general monitoring programme is unlikely to reveal such "hot-spots". On the other hand, contamination over large areas, or due to aerial fallout from distant sources, may be detected in a general survey.

The information obtained must, however, be sufficiently accurate to establish statistically that levels of contamination appearing to be high are in fact high, by comparison with those in other areas. Similarly, it should be possible for changes in the contamination level from year to year to be detected with appropriate statistical significance. Such information is of value in assessing the consequences of government or industrial action which has been taken to reduce pollution. The accuracy of the estimates of contamination levels depends, in part, on the precision of the analyses, which in turn is dependent on the experience and efficiency of the analysts.

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In large-scale monitoring programmes many analysts will be involved, but an adequate assessment of their agreement can be obtained by the use of exchange samples.

Finally, the acquisition of analytical data is not the ultimate purpose of monitoring. The underlying fear is that contamination levels may be sufficient to have adverse biological effects at one or more points in an eco-system, but as yet adequate evidence of such effects has been established in very few instances. It is essential that the concentrations in various species which are capable of causing adverse effects should be determined, whether the effects are for example, reduced photosynthetic activity in algae, the failure to reproduce in invertebrates, abnormal behaviour in vertebrates, or mortality in any species.

OECD STUDIES OF MONITORING

The Organisation for Economic Co-operation and Development (OECD), in a series of international collaborative studies on the monitoring of organochlorine residues in the environment, has attempted to examine some of the problems referred to in the preceding paragraphs.

In the second programme (Holden, 1970), the ability of analysts in several countries to obtain the same results, both qualitatively and quantitatively, in the analysis of exchange samples was measured. At that time (1968-69), the variation between analysts increased with the difficulty of processing the samples, and for the only residues in which there was general agreement on identity (dieldrin, DDE, TDE and DDT), the coefficient of variation was ±25 to ±60%. In the third programme (Holden, in preparation) a substantial improvement was noted for the period 1969-71, the coefficient of variation for six pesticide residues and PCBs in samples requiring full processing being ±10 to ±10% among 17 laboratories.

The question of the number of individuals of a population required to provide a mean value of sufficient precision for detecting differences between populations, or changes from year to year, was also examined in the second programme. In both sterling and pike populations (with no selection for age or sex), fifty individuals would have been required to detect a 2% difference between means, but ten would have been

sufficient to detect a 75% difference. The main reason for such low precision was that the residues in the individuals were usually clearly distributed, but this may have been due to the variation in age within samples.

The third study programme included the analysis of PCB residues in addition to organochlorine pesticide residues in selected wildlife species, and samples were taken from uncontaminated and contaminated areas. The results of this programme have provided information on the extent of PCB contamination, and also on the difficulty of identifying the contaminated areas.

It must be borne in mind that, in common with all other PCB analyses at the present time, the values obtained are estimates of the total PCB concentration expressed in terms of a commercial mixture of specified chlorine content. The proportions of the various isomers and homologues present in the samples usually differ from those in the commercial mixtures, and no information on the concentrations of individual compounds is afforded by the analysis. The assessment of the potential toxicity of the residues detected is thus rendered difficult, and any such estimate must be regarded with caution.

Ten countries sampled and analysed the mussel (Mytilus edulis) in coastal waters, both in areas considered to be uncontaminated and in other areas known to be polluted. The assessment of pollution varies considerably, some polluted areas giving PCB concentration in muscle as low as 0.02mg/kg, and the unpolluted area giving 0.5mg/kg. Areas with varying degrees of pollution gave values of 0.02 - 1.7mg/kg. A similar situation arose with the samples of herring (Clupea harengus) analysed by eight countries. Those from areas classed as unpolluted had PCB concentrations in muscle tissue ranging from 0.10 to 0.54mg/kg, but the range in fish from polluted areas was 0.19 to 3.2mg/kg.

Freshwater fish show less evidence of PCB contamination. The pike (Esox lucius) sampled in six countries usually contained little PCB even in polluted waters, the values generally being less than 0.1mg/kg. Yet where serious pollution by PCB exists the concentrations can be much higher, as in the samples analysed by the Netherlands, with PCB levels of 0.47 - 0.95mg/kg.

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The eggs of fish-eating birds can demonstrate the accumulation of organochlorine residues from their food very effectively. Eggs of the heron *Ardea cinerea* were analysed by the United Kingdom and the Netherlands. In samples from remote areas of the United Kingdom concentrations below 0.5µg/kg were found in the eggs, with up to 7.3mg/kg in a very polluted area. In the Netherlands the concentrations in polluted areas were up to ten times greater, 33 - 74mg/kg. This ability to concentrate residues in eggs was also shown by the samples from two common tern (*Sterna hirundo*) colonies in Canada. The relatively uncontaminated colony gave .2 - 4mg/kg PCB but that in a polluted area contained a mean of 149mg/kg in eggs.

DISCUSSION

The third OECD programme has indicated the difficulties of identifying areas polluted by organochlorines, and in particular PCB, by evidence other than chemical analysis. Consequently the identification of local sources of PCB pollution by the analysis of indicator or monitoring species would entail a very large and detailed sampling and analytical programme involving numerous sites. On the other hand, the detection of more general pollution over large areas, if such pollution exists, should be disclosed by a pattern of fewer sampling sites at which an appropriate species could be used for monitoring on a regular basis. Ideally, this species should accumulate the contaminants to such an extent that there is a considerable difference between PCB content of uncontaminated and polluted specimens. The species should therefore be relatively resistant to the effects of the pollutant.

Referring to the information provided by the second OECD study, concentrations of PCB in muscle showed an overall range of about 1:100, with only a 1:30 range for herring. The eggs of herons showed at least a range of 1:150, and an even greater range might be revealed by further samples. A heron in the Stockholm Archipelago was found by Jensen *et al* (1969) to contain 9,400mg/kg in muscle, which suggests that eggs from such birds could also contain exceptionally high levels.

While eggs may be particularly useful in revealing areas of pollution, the numbers available for analysis could be limited. On the other hand species such as muscle or

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herring can usually be collected in quantity. The greater precision of the estimation of the mean level of contamination of a population of mussels, herring or similarly abundant species could therefore be as important in the choice of a monitoring species as the wider range of contamination levels likely to occur in the eggs of piscivorous birds.

A further restriction is placed on sampling by the habitat of the species. Mussels can only be collected from coastal waters, for example, and seals, in which extremes in contamination level have also been demonstrated (Holden, 1972) are limited in their distribution. As many seal colonies are protected, it may be difficult to acquire more than a few specimens for analysis. The major problem which arises in the selection of an appropriate monitoring species for global surveillance, however, is that very few occur in all areas of the world, although an ecologically equivalent species can often extend the range. Species which seem ideal from many points of view (adequate numbers, ease of sex and age determination, ease of sampling) may be limited to the northern hemisphere, or to one continent. Marine species are sometimes more widespread, but clearly cannot reflect contamination in terrestrial or fresh water environments, where pollution may originate.

The OECD studies have enabled some assessment to be made of analytical accuracy, of the ability to obtain samples of chosen species in the required numbers (or of the attendant difficulties), and of the ranges of various residues which exist in polluted and unpolluted areas. They have also shown the difficulty of positively identifying such areas prior to performing the analyses. In particular, the choice of species which would be appropriate for global monitoring has been under constant discussion, and no species has yet been proposed which meets all the requirements for such a purpose. It is likely that a wide variety of species must eventually be proposed, the assessment of the extent of pollution being based on the results from several species in each area, rather than on any particular species.

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A Summary of NWQL Research Concerning the Effects of Polychlorinated Biphenyl on Water Quality and Aquatic Life

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Environmental Protection Agency

National Water Quality Laboratory

Duluth, Minnesota

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Exposure of Brook Trout to Aroclor® 1254

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Brook Trout are being exposed to Aroclor® 1254 to determine the effects of sublethal water concentrations of PCBs on growth, reproduction, hatchability, and survival of fry through absorption of the yolk-sac. The analysis for PCBs in tissue has been included to study the amount concentrated by the fish and its transfer to the eggs. Tissue analysis include measurements in muscle, gonads, and the whole body and during spawning in the eggs. Spawning is expected to occur after 15 months of exposure.

No effect on growth or survival has been observed during the first 9 months of this test. Data were obtained from sacrifices after 14 and 27 weeks of this exposure and after 8 and 14 weeks of a previous exposure terminated before completion.

The residue data from the trout exposed for 27 weeks indicate that approximately 0.55 µg/l of Aroclor® 1254 will result in 5 µg/gm of the PCB mixture in the fish (whole fish basis). The concentration in the fillet of fish exposed to 0.84 µg/l Aroclor® 1254 was 1 µg/gm. The lipid content of the fillet portion of the trout was less than two percent.

Figure 1 shows the relationship between the concentration of PCBs in water and the concentration in the tissue (wet). The linear regression lines suggest the concentration in the tissue to be directly proportional to the concentration in the water. The spread shown by these lines indicates a range of PCBs in various tissues for each water concentration. Note that similar tissues are clustered into narrow

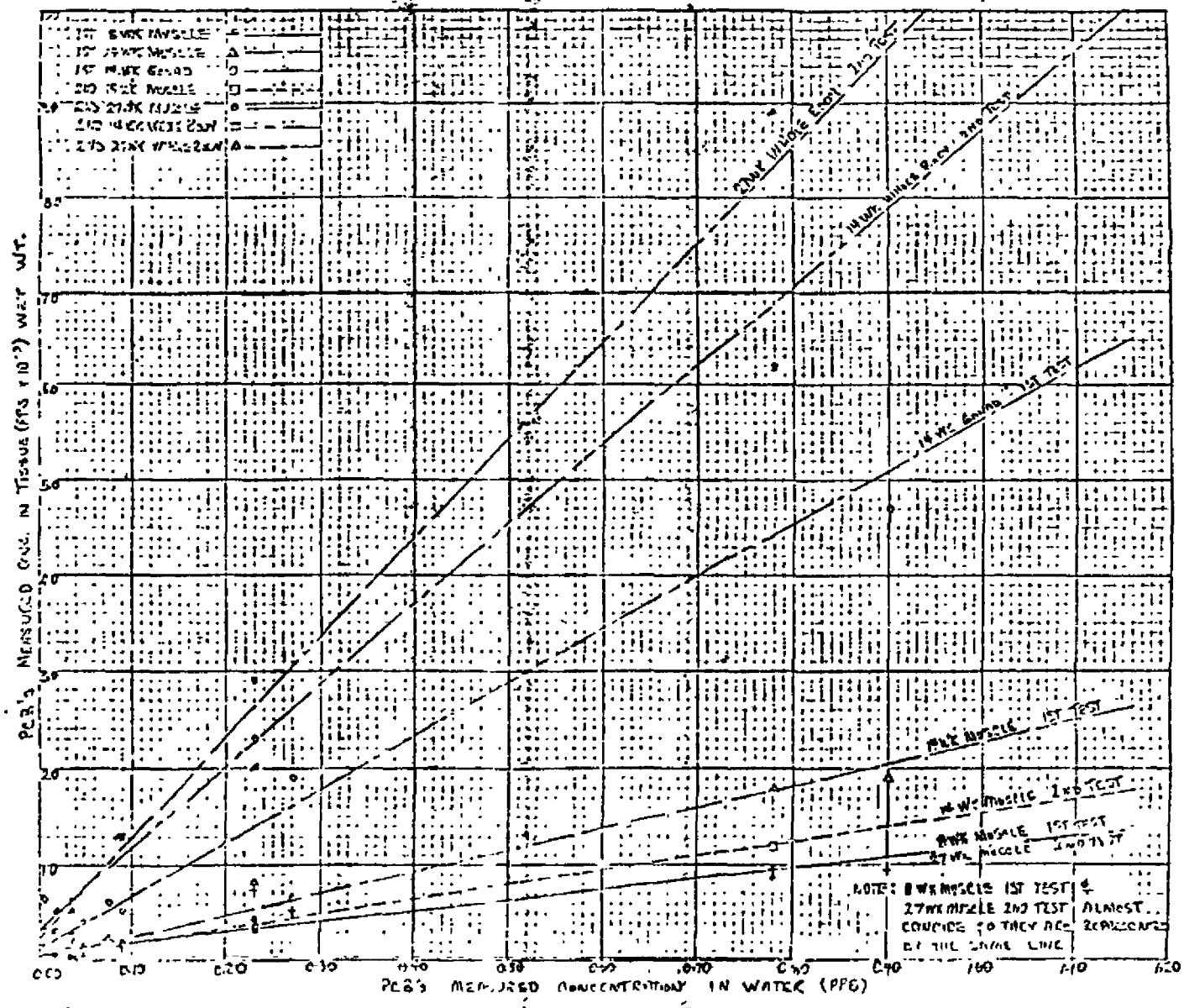

FIGURE 1 RELATIONSHIP OF PCB'S IN WATER TO PCB'S IN TISSUE

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bands of the entire range.

The concentration of PCBs in the tissue appears to be correlated to the lipid content of the tissue as indicated by Figure 2 which shows the relationship between water concentrations and PCB concentrations calculated on a lipid weight basis. Again, the PCBs in the lipid are directly proportional to the concentration in the water. The variability in concentrations in lipid is much less than the variability in the tissue based on wet weight. This suggests that the PCB level in the tissues result, in part, from the partitioning between the lipid and water.

The concentrations of Aroclor® 1254 in the brook trout lipid ranged from 110,000 to 170,000 times greater than the concentration in the water and was largely independent of the length of exposure after 14 weeks.

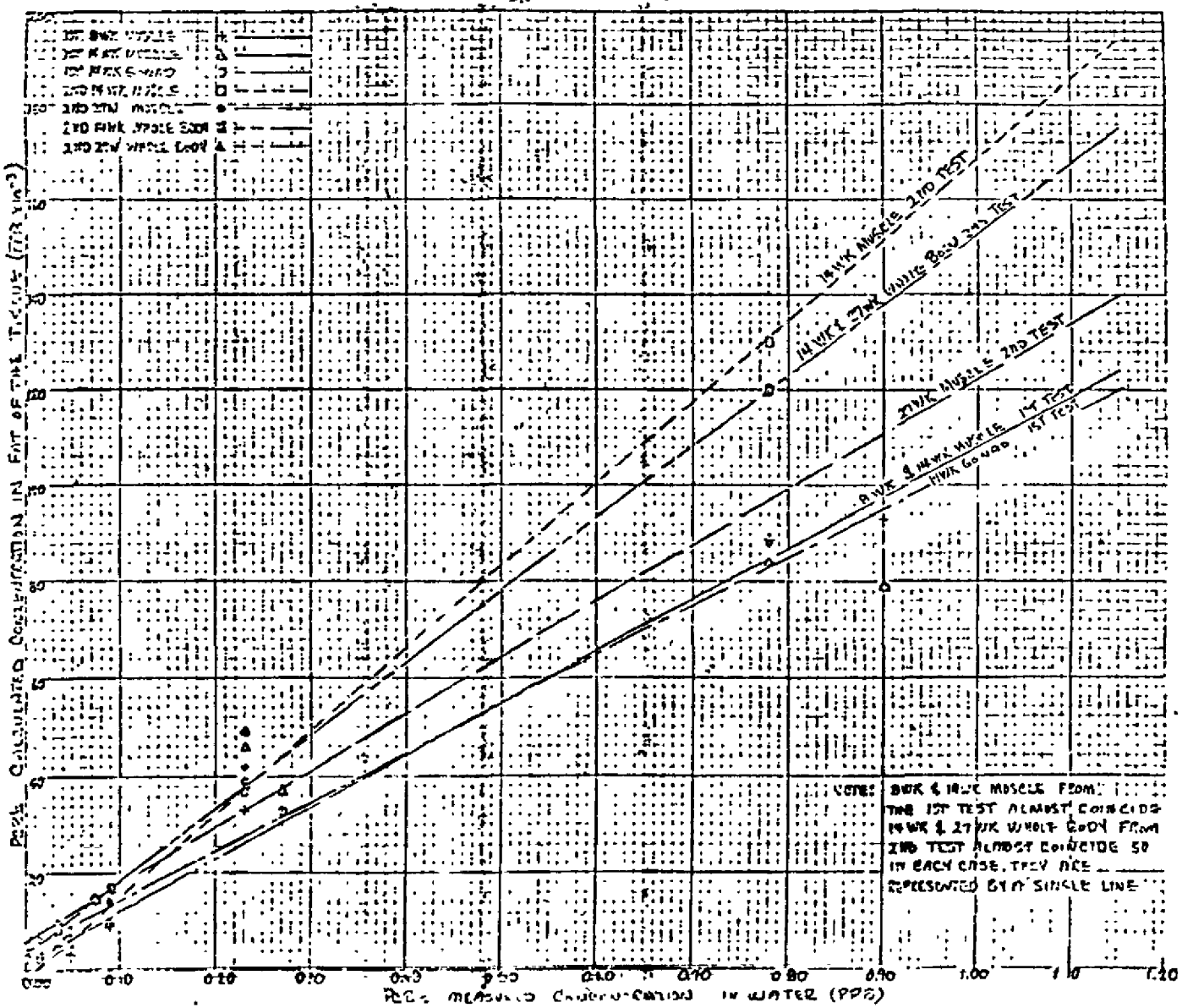

FIGURE 2 RELATIONSHIP OF PCB'S IN WATER TO PCB'S IN FAT

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Exposure of Fathead Minnows to Aroclor® 1248 and 1260

D. L. Defoe, R. W. Carlson and G. D. Veith

Chronic exposures of PCB Aroclors® 1248 and 1260 to the fathead minnow have been completed. The data is being analyzed and prepared for publication.

The data presented herein which represent mean values of duplicate bioassays are normalized to the results obtained with the control fish exposed only to the acetone carrier.

More detailed studies to determine the effect of carriers on the bioassay results are underway.

The 30 day acute exposures using Aroclor® 1248 and fathead minnow fry (less than 12 hours old) has shown that 8 µg/l of A 1248 killed all the fry, 4.5 µg/l killed 50 percent of the fry and caused a 70 percent reduction in the weight of the fry, and 2.2 µg/l caused no mortality but a 20 percent reduction in weight. Similar studies with Aroclor® 1260 demonstrated that 9 µg/l killed all the fry and 4 µg/l caused 70 percent mortality and a 30 percent reduction in fry weight.

The reproduction, measured as the number of eggs spawned per female, in females exposed to 1.1 µg/l Aroclor® 1248 were only 60 percent of that of the controls. Aroclor® 1260 did not affect reproduction at concentrations up to 2.1 µg/l.

The second generation fry from adults previously exposed to the PCB mixtures were exposed to the respective mixtures for 30 days after hatching. Preliminary data analyses indicated that 3 µg/l of Aroclor® 1248

caused no mortality but a 20 percent reduction in the weight of the fry. Similarly, Aroclor® 1260 caused no mortality when the fry were exposed to 2.1 µg/l; however, the weight of the fry was reduced by 33 percent.

Figure 3 indicates that the concentration of both Aroclor® 1248 and 1260 in the male fathead minnows reached an apparent steady-state after the first 100 days. The concentration of the PCBs in the female fish was more than double that in the male when expressed on a wet weight basis. However, the concentrations expressed on a lipid basis as illustrated in Figure 4 indicate that the females contained slightly less PCB per gram of lipid than did the males. In addition, the PCB concentration in the female on a wet weight basis was much more variable than the male, presumably due to the variable lipid content of the female.

The fathead minnow accumulated Aroclor® 1260 concentrations (lipid basis) approximately 270,000 times that in the water, whereas Aroclor® 1248 was accumulated to lipid concentrations approximately 120,000 times that in the water.

Data analyses and studies concerning the 60 day growth, delays in spawning, egg hatchability, body burden of PCBs, and the elimination of PCBs from the fish are continuing.

Figure 3
Accumulation of Aroclor 1248 and 1260
in Fathead Minnows

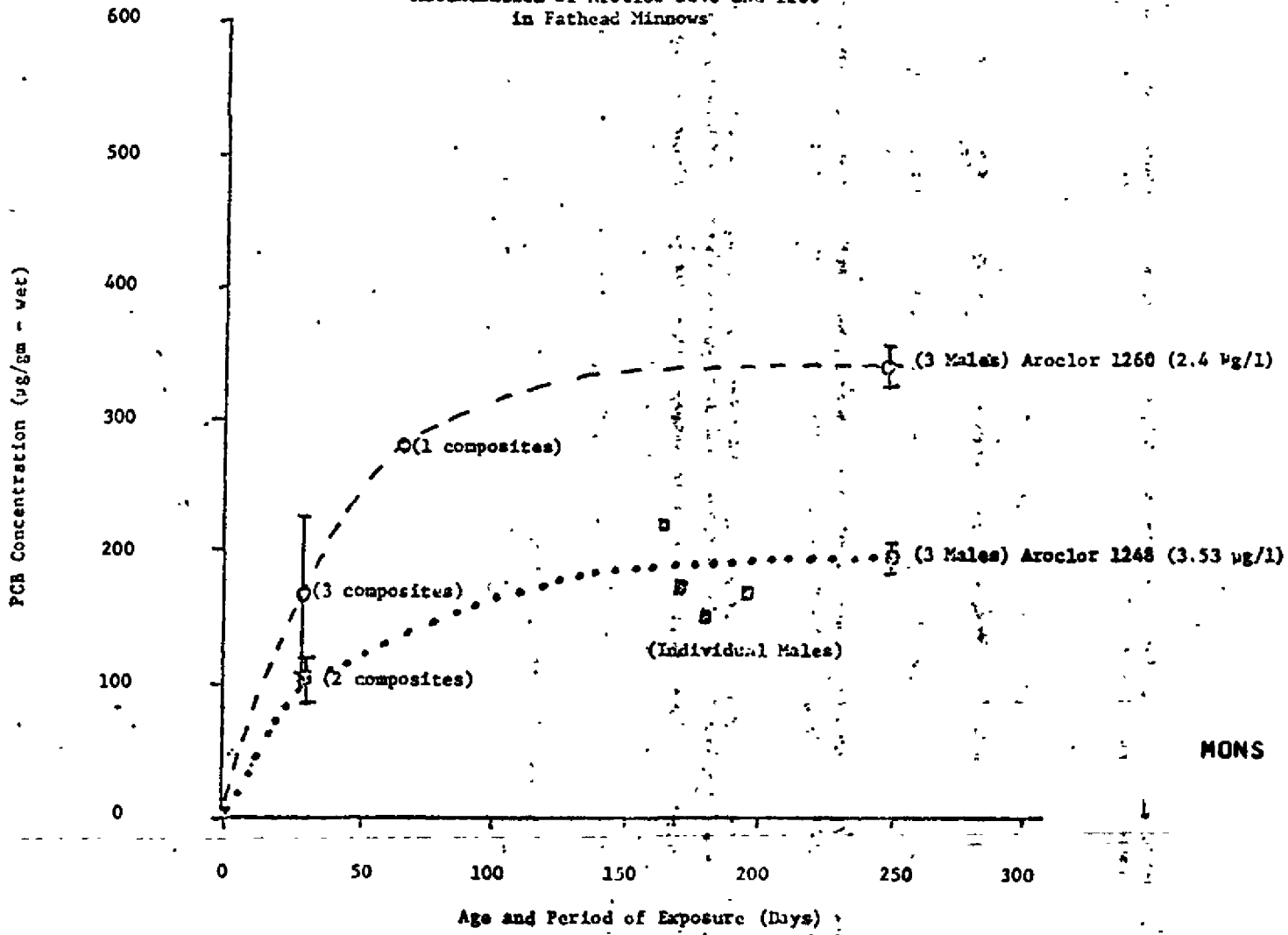

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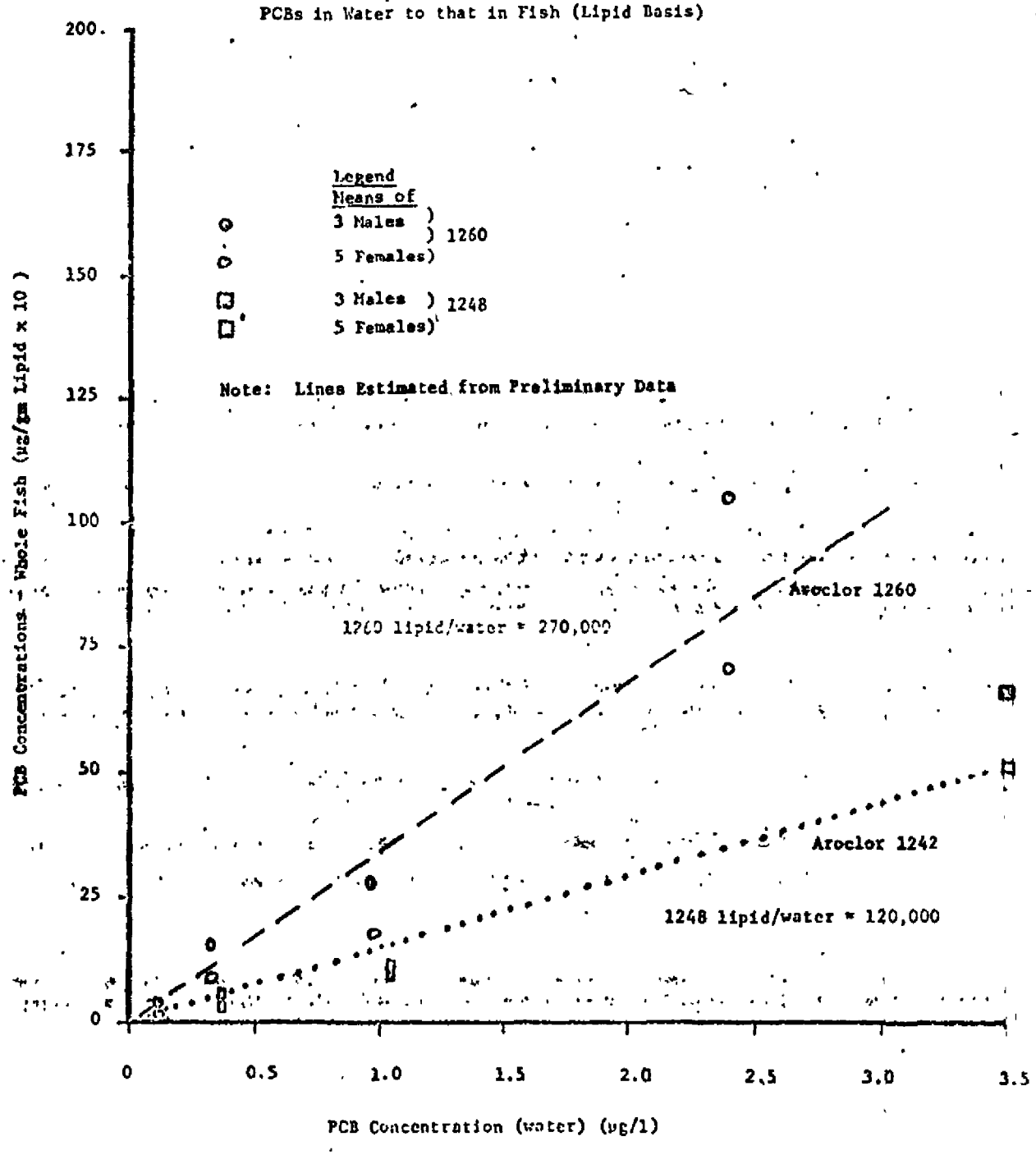
Figure 4
Relationship Between the Concentration of
PCBs in Water to that in Fish (Lipid Basis)



Summary of Other Exploratory Studies with PCBs

A. V. Nebeker, F. A. Puglisi and D. L. DeFoe

As indicated in Table 1, Aroclor 1248 was the most toxic of the eight aroclors tested to Daphnia magna in static tests, with a 3-week LC50 of 25 µg/liter. Aroclor 1254 was most toxic under continuous-flow conditions with a 3-week LC50 of 1.3 µg/liter. The Aroclors were more toxic under continuous-flow than static conditions, with 16 percent impairment of reproduction caused by 1.0 µg/liter Aroclor 1248.

The calculated 96-hour LC50 values for newly-hatched fathead minnows were 7.7 µg/l for Aroclor 1254 and 15 µg/l for 1242. Three-month-old fatheads had a 96-hour LC50 of ca. 300 µg/l for 1242. Reproduction occurred at and below 1.8 µg/l 1254 and at and below 5.4 µg/l 1242. Polychlorinated biphenyls were acutely toxic but exhibited much greater chronic toxicity at very low levels, due to their cumulative nature. Newly hatched young were the most sensitive life stage. Young fathead growth was also affected above 2.2 µg/l 1248 and none survived above 5.1 µg/l after 30 days. Young flagfish, Jordanella floridae, did not survive above 5.1 µg/l 1248 and did not grow well above 2.2 µg/l.

The ninety-six hour LC50 values for Aroclor 1242 and 1248 with Gammarus pseudolimnaeus were 73 and 29 µg/liter. Survival after 30 days was 53 percent at 8.7 µg/l 1242 and 52 percent at 5.1 µg/l 1248. Good reproduction and survival of young occurred at 2.8 µg/l 1242 and 2.2µg/l 1248.

MONS 203885

Table 1. The Comparative Toxicity of Eight Aroclors[a] (in µg/liter) to Daphnia magna in Lake Superior Water as Determined in Static Test Conditions

Aroclor	Three Week LC50	Confidence Limits[b]	Reproductive Impairment 50%	Confidence Limits	16%	Confidence Limits
1221	180	158-205	125	116-135	89	85.6-92.6
1232	72	62.6-82.8	66	60-72.6	53	50.5-55.7
1242	67	55.4-81	63	56.3-70.5	48	45.2-50.9
1248	25	21.4-29.2	24	21.2-27.1	16	13.9-18.4
1254	31	26.8-37.2	28	23.1-33.9	18	14.5-22.3
1260	36	27.7-46.8	33	27.5-39.6	22	17.7-27.3
1262	43	37-49.9	41	33-53.3	24	17.6-32.6
1268	253	222-288	206	185-228	162	146-179

[a]Polychlorinated Biphenyls: Aroclor 1221-1268., Monsanto Chemical Company, St. Louis, Mo.

[b]Ninety-five percent confidence limits.

Abundant adult emergence of the midge Tanytarsus dissimilis did not occur above 5 µg/1 1248 or 3.5 µg/1 1254. The calculated 3-week LC50 (50 percent reduction based on control as 100 percent) for Aroclor 1254 was 0.65 µg/1 for larvae and .45 µg/1 for pupae.

Application factors of 0.10 for 1242 and 0.15 for 1248 were calculated for the PCB's and Cammarus. Application factors of 0.2 for 1254 and 0.16 for 1242 were calculated for fathead minnows using newly hatched fish to obtain the 96-hour LC50.

Survival and Reproduction of Daphnia magna After Three Week Exposure to PCB Mixtures

L. Uhlken, R. W. Carlson

Studies have been initiated to determine the relativity toxicities of individual chlorobiphenyls, simplified mixtures, and Aroclor® 1016 to Daphnia magna. As shown by previous studies, the toxicity of the PCBs increases with increasing chlorine content. For example, Daphnids exposed to 50 µg/l 2,2'-dichlorobiphenyl produced 515 young whereas those exposed to the same weight of a mixture of trichlorobiphenyls produced only 111 young. Daphnids exposed to tetrachlorobiphenyls and Aroclor® 1242 at the 50 µg/l did not survive.

Preliminary data suggests that some mixtures of trichloro-and tetrachlorobiphenyls may be as toxic as Aroclor® 1242. Studies with Aroclor® 1016 are continuing.

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MAY 28 1974

Effect of Polychlorinated Biphenyl Compounds on Survival and Reproduction of the Fathead Minnow and Flagfish.

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Trans. Amer. Fish. Soc. 103(3): July, 1974

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Abstract

Two 9-month continuous-flow bioassays and several intermediate length continuous-flow tests were conducted to determine safe levels of Aroclor 1242, 1248, and 1254 for the fathead minnow (Pimephales promelas) and Aroclor 1248 for the flagfish, Jordanella floridae. Calculated 96-hour LC50 values for newly hatched fathead minnows were 7.7 µg/liter for Aroclor 1254 and 15 µg/liter for 1242. Three-month-old fatheads had a 96-hour LC50 of 300 µg/liter for 1242. Reproduction occurred at and below 1.8 µg/liter 1254 and at and below 5.4 µg/liter 1242. Newly hatched young were the most sensitive life stage. Growth of young fatheads was also affected above 2.2 µg/liter 1248, and none survived above 5.1 µg/liter after 30 days. Young flagfish did not survive at 1248 concentrations above 5.1 µg/liter and did not grow well above 2.2 µg/liter.

Tissue residues in fathead minnows ranged from 0.7 µg/g 1248 in control fish to 1036 µg/g 1254 in fish held for 8 months in water containing 4.6 µg/liter 1254.

MONS 203890

Introduction

Polychlorinated biphenyl compounds (PCB's) are among the many exotic chemicals now finding their way into our waters. They are detected in fish and other aquatic organisms at concentrations much higher than those found in the ambient water. Because analytical methodology for detecting and identifying low levels of PCB's in water and aquatic organisms has only recently become available, little is known about the interactions. The acute toxicities of some of the PCB's produced commercially are presently being demonstrated at the Fish-Pecticide Laboratory, USDI, Columbia, Missouri (Stalling 1970); the Gulf Breeze Laboratory, EPA, Gulf Breeze, Florida (Duke et al. 1970); and the National Water Quality Laboratory, EPA, Duluth, Minnesota (Nebeker et al. 1972). The effects of PCB's on reproduction of Daphnia magna, Gammarus pseudolimnaeus, and the midge Tanytarsus dissimilis have been detailed by Nebeker and Puglisi (In press), but no full life-cycle information is available for fish species.

This study was begun in October 1970 to determine the effects of three PCB's, Aroclor 1242, 1248, and 1254, on the survival, growth, and reproduction of the fathead minnow (Pimephales promelas) and the effects of Aroclor 1248 on the survival and growth of the flagfish, Jordanella floridae. Further studies were conducted to determine the effects of Aroclor 1242 and 1254 on maturation, egg production, egg hatch, young production, and survival of young of the fathead minnow. Tissue residues were also determined to measure uptake of PCB's.

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Materials and Methods

Physical Testing Methods

Three continuous-flow testing units were used, each consisting of five duplicated test concentrations and a control. Stainless steel and glass aquaria were used for all test chambers. Twelve 10-gallon aquaria were used for adult fish in the Aroclor 1254 testing; twelve 5-gallon aquaria were used for Aroclor 1242 testing; and twenty-four 2 1/2-gallon aquaria were used for testing Jordanella and some young fathead minnows. Young fish from spawning tanks were tested in 5- and 2 1/2-gallon aquaria. Three proportional diluters (Mount and Brungs 1967) provided the necessary continuous-flow conditions. A modification of the diluter system, a gas syringe filled with acetone and PCB, was used with a mechanical injector system to deliver the toxicant to the mixing chamber of the diluter. Agitation was maintained by circulating the mixing box contents through a submersible pump. Additional mixing boxes, with two-way and four-way splits to the duplicate test aquaria, provided further mixing of the PCB solutions. All tanks were randomly distributed on the test tables. Raw Lake Superior water was used for all testing.

The diluters delivered 350 ml (1242), 200 ml (1254), and 150 ml (1248) to each tank every 3 minutes; flow rates were set primarily to maintain adequate dissolved oxygen concentrations. These flow rates ensured a complete exchange of water in the test tanks every 4-5 hours. All tanks were cleaned daily, and excess algal and bacterial growths were scraped away weekly.

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Spawning substrates for fathead minnows consisted of inverted 3-inch-long logitudinal sections of glass quart beverage bottles. Egg hatchability studies were conducted in the same manner as previous fathead studies by Mount (1968), Brungs (1969), and others.

Temperatures were maintained at 24 ± 1 C. Durotest[2] (Optima FS) and wide spectrum Grow-lux fluorescent tubes provided light. The photoperiod of Evansville, Indiana, was maintained, with the adjustments in day length made every 2 weeks, as recommended by the National Water Quality Laboratory Committee on Aquatic Bioassays (Bioassay Committee MS 1971).

[2] Mention of commercial products does not constitute endorsement by the U. S. Environmental Protection Agency.

Biological Methods

All fish were obtained from stocks at the National Water Quality Laboratory in Duluth, Minn. Ninety-six-hour acute tests with various ages of fish, conducted according to standard methods (American Public Health Association 1965), and chronic tests were carried out to obtain information for future calculation of application factors. Measured PCB concentrations were used for all calculations.

Full life-cycle studies with the fathead minnows (Aroclor 1242 and 1254) and the tests with Jordanella (1248) were started with newly hatched young (< 24 hours old). In the 30-day Jordanella test observations on survival were made daily, and growth was measured at the end of the test. Young fathead minnows were tested in the same diluter system, but in different tanks, at the same time to get comparative information on the two species.

Fathead (full life-cycle) testing was begun with 40 newly hatched young per concentration, 20 fish in each aquarium. They were fed twice daily with newly hatched live brine shrimp, frozen brine shrimp, Daphnia, and dry and frozen commercial fish foods. Growth was measured photographically (McKim and Benoit 1971) at 60 and 90 days and at the end of the test. Prior to sexual maturation five spawning substrates were placed in the aquaria, and the fish were thinned to leave 10 fish per tank. The fish that were removed were used to study the effects of PCB's on adenosine triphosphatase activity (Cutkomp and Koch In press).

Eggs laid on the spawning substrates were removed, counted, and placed in egg cups for hatchability testing. Twenty-five or fifty eggs were placed in cups, and the number hatched was recorded. Some of the newly hatched fish were transferred to smaller aquaria at the same concentrations and held for 30 days to determine survival and growth.

MONS 203895

Analytical Methods

The ploychlorinated biphenyls tested were Aroclor 1242, 1248, and 1254, manufactured by Monsanto Chemical Company. The stock solutions were prepared by weighing the compound and dissolving it in acetone.

Six liters of test water were collected from each test concentration to be analyzed. Three liters were siphoned into each of two 1-gallon glass bottles to provide duplicate samples. Tefion-lined screw caps were constructed for the bottles. A duplicate of the control and at least one other sample were spiked with equal amounts of the toxicant being used in the system. Ten milliliters of concentrated sulfuric acid and 300 ml of glass-distilled methylene chloride were added to each sample. The caps were then tightened and the bottles placed on a mechanical shaker for 10 minutes. The samples were allowed to settle for at least 10 minutes before the aqueous phase was decanted. The organic phase and remaining water were transferred to a separatory funnel and again allowed to settle. The organic layer was drained through solvent-washed anhydrous sodium sulfate into a Kunderna-Danish evaporator. The solvent was evaporated on a steam bath until the entire sample was contained in the 10 ml evaporator receiver. The remaining solvent was evaporated by blowing a gentle stream of dry nitrogen over it until the first sign of dryness. The receiver was stoppered with a cork wrapped in acetone-washed aluminum foil and stored for gas chromatograph (G.C.) analysis.

Analysis was done on a Tracor MT-220 gas chromatograph with a 6-foot 1/4-inch OD glass column packed with 3% OV-1 chromosorb W 80/90 mesh. A Coulson conductivity detector was used in the reductive mode without a catalyst. Sixty ml/min helium carrier gas was used with a 10 ml/min helium purge through the furnace when the column was vented. A rate of 40 ml/min of electrolytic hydrogen was used for the reductive pyrolysis. The temperatures of the inlet and all transfer lines were kept at 260 C, and the column varied from 195 C to 205 C depending on the PCB mixture being measured. The pyrolysis furnace was kept at 820 C.

The residue was dissolved in a volume of n-hexane that would give a concentration such that a 50-microliter injection would give at least 25% scale response on a 1-millivolt chart recorder. The solvent was vented to prevent it from contaminating the furnace.

A single well-defined peak (Figure 1), present in all three of the PCB's tested, was used as an internal standard and was compared to the same peak in the "standard." This "quantitation" was done by alternately injecting standards and samples making sure the standards response (peak height) bracketed the response of the sample injected between them. The responses were plotted on linear graph paper, and the unknown quantity was taken from the plot. The calculated concentrations were corrected for recovery by using the ratio of the difference between the spiked and unspiked duplicate samples to the size of the spike. Mean measured concentrations were used for all calculations of biological data.

The extraction efficiencies of this method are presented in a previous report (Nebeker et al. 1972). The recovery values based on the single-peak evaluation show little difference in the Aroclors. This indicates that the extraction of the compound represented by the peak may be only slightly affected by the other compounds present.

The variability of this method on duplicate samples is less than 10%, regardless of concentration of toxicant. The variability of G.C. injection was less than 5% for duplicate injections of the standard or the same residue and up to 10% for injections of different volumes of the same residue.

A comparison of nominal and measured concentrations for all three Aroclors (Nebeker et al. 1972) indicated that, except for a few high values, the diluter systems were working well.

A standard, one/two factor analysis of variance program (ANOVA) written for the CDC 3300 was used to test for experimental differences.

Chemical characteristics of the Lake Superior Test water, measured daily or weekly with Standard Methods (American Public Health Association 1965), were as follows: pH, 7.5-8.0; acidity, 2.4-4.0 mg/liter; alkalinity, 40-43 mg/liter (as $CaCO_3$); calcium hardness, 34-36 mg/liter; and total hardness, 44-46 mg/liter.

Terminal residues of Aroclor 1242 and 1254 in fathead minnows were determined by the Fish-Pesticide Laboratory, Columbia, Missouri, using the methods of Stalling and Johnson (1971). Residues of PCB's in feed used in tests was also determined (Table 9).

Results

Fathead Minnow - Aroclor 1242

Concentrations of Aroclor 1242 above 10 µg/liter were lethal to newly hatched fry. Calculated 96-hr LC50 values for Aroclor 1242 were 15 µg/liter for newly hatched young fathead minnows and greater than 234 µg/liter (near 300 µg/liter) for 2-month-old fish. All minnows in the long-term study were dead after 96 hours in 51 µg/liter 1242, and none survived to the end of the test (8 months) at 15 µg/liter. Survival of fry was excellent when reared at the same concentrations their parents lived and spawned at. The final weights and total lengths of the fish did not differ significantly at the end of the 8-month test, however, growth of newly hatched fish was retarded prior to their death at the higher PCB concentrations.

Reproduction occurred at and below 5.4 µg/liter 1242 but spawning results and egg production were highly variable (Table 1) even when numbers of males and females were the same in some duplicate tanks. Egg hatchability was also variable but good hatching occurred at 5.4 µg/liter. Eggs were more resistant than fry at 15 and 51 mg/liter. Eggs produced by the controls but maintained at the higher concentrations hatched with good success, but none of the fry survived.

Terminal residues of Aroclor 1242 in fathead minnows exposed for 8.5 months are given in Table 5 (controls - Table 7).

Fathead Minnow - Aroclor 1248

Fathead minnows died rapidly at 18 µg/liter Aroclor 1248, and none was alive at the end of a 30-day test. Seventy-five percent were alive at 5.1 µg/liter, but their weight was only one-third that

of the controls; their final lengths were not significantly different, however.

The final weight of the fish in 2.2 µg/liter was only half that of the controls; final lengths were the same. The results in the two lowest concentrations (0.54 and 0.18 µg/liter) were not significantly different from the controls.

Fathead Minnow - Aroclor 1254

Aroclor 1254 was more toxic to the fathead minnow than 1242 as they did not survive and reproduce above 1.8 µg/liter 1254.

Calculated 96-hr LC50 values for Aroclor 1254 were 7.7 µg/liter for newly hatched young fathead minnows and greater than 33 µg/liter for 2-month-old fish. All fish in the long-term reproduction study were dead after 96 hours in 15 µg/liter 1254 in both tanks. Survival at lower concentrations was not significantly different from the controls. The mean terminal weights of the fish were not significantly different in the various concentrations, but growth in length was delayed at 4.6 µg/liter. Spawning occurred at 1.8 µg/liter, but was significantly less than that at lower concentrations. Spawning was variable during the test, even between duplicate tanks (Table 2).

Egg hatchability and fry survival were good at and below 1.8 µg/liter (Table 3). Eggs produced by the controls and maintained in higher PCB concentrations (15 µg/liter) hatched readily, but all young were dead within 96 hours. Young fish which were held for 30 days in separate tanks at the same PCB concentrations at which they were spawned survived and grew well.

MONS 203900

Terminal residues of Aroclor 1254 in fathead minnows exposed for 8 months are given in Table 6 (controls - Table 8).

Jordanella - Aroclor 1248

Fish held in 18 µg/liter Aroclor 1248 lived for about 2 weeks before they started to die. One died every 2-3 days until all were dead at the end of the 40-day test. Thirty-five percent were alive at 5.1 µg/liter at the end of the test; mean weight was only 15% that of the controls (Table 4). Mean length at 5.1 µg/liter was 21.8 mm, compared to 24.6 mm for the controls.

The fish in 18 and 5.1 µg/liter 1248 lost their fins and tail almost completely, as if they had been eroded away. The death of the one remaining fish at 18 µg/liter and three fish in 5.1 µg/liter when the temperature dropped from 25 C to 21 C indicates the precarious condition of the fish even though they were still alive.

Discussion

The results obtained from this study indicate that polychlorinated biphenyls are acutely toxic, and cause chronic toxicity at very low levels. The newly hatched larvae apparently are the most sensitive stage in the life cycle, at least for short-term exposure. The eggs were resistant or impermeable to the PCB mixtures. The inhibition by the PCB mixtures of bacterial-fungal growths on the incubating eggs resulted in a much better egg hatch at higher PCB levels. Juvenile fish, when tested for up to 30 days, were much less susceptible than very young fish. Tissue residues were very high in test fish, with some fish containing more than 200,000 times as much PCB as the water they were tested in.

MONS 203902

Acknowledgments

We wish to thank Henry Bell, Wesley Smith, and Allan Batterman for aid during testing, Dr. David L. Stalling for residue analysis of fish tissues, and Dr. Kenneth Biesinger and Kenneth Dyram for helpful suggestions and statistical assistance. We also thank Monsanto Chemical Company for their cooperation and for making Aroclor samples available for testing.

MONS 203903

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MONS 203904

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MONS 203905

Table 1. Spawning and egg production of the fathead minnow at various concentrations of Aroclor 1242

Mean measured concentration (µg/liter)	Test tanks	Number of males	Number of females	Number of spawnings	Number of spawnings per female	Total eggs produced	Number of eggs per spawning	Number of eggs per female
51	A	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0
15	A	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0
5.4	A	4	5	25	5.0	1,514	61	303
	B	4	6	0	0	0	0	0
2.9	A	5	4	24	6.0	1,923	80	481
	B	4	5	9	1.8	424	47	85
0.86	A	6	4	5	1.3	138	28	35
	B*	—	—	—	—	—	—	—
0.0 (control)	A	1	8	42	5.2	5,350	127	669
	B	3	6	24	4.0	1,288	54	215

*Accidentally killed.

MONS 203906

Table 2. Spawning and egg production of the fathead minnow at various concentrations of Aroclor 1254.

Mean measured concentration (ug/liter)	Test tanks	Number of males	Number of females	Number of spawnings	Number of spawnings per female	Total eggs produced	Number of eggs per spawning	Number of eggs per female
15	A	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0
4.6	A	4	5	0	0	0	0	0
	B	1	5	0	0	0	0	0
1.8	A	3	7	14	2.0	1,473	105	210
	B	4	7	1	0.14	22	22	3
0.52	A	4	6	30	5.0	4,142	138	690
	B	4	6	33	5.5	2,538	77	423
0.23	A	1	8	35	4.4	2,993	86	374
	B	5	5	8	1.6	346	43	69
0.0 (control)	A	3	6	27	4.5	2,838	105	473
	B	4	6	2	0.3	206	103	34

MONS 203907

Table 3. Egg hatchability and fry survival of the fathead and DeFoe minnow at various concentrations of Aroclor 1254

Mean measured concentration (µg/liter)	Test tanks	Number of eggs used	Number of live fry obtained	Egg hatchability (%)
15	A	0	0	0
	B	0	0	0
4.6	A	0	0	0
	B	0	0	0
1.8	A	300	186	62
	B	50	48	96
0.52	A	375	251	67
	B	345	205	59
0.23	A	272	150	55
	B	0	0	0
0.0 (control)	A	250	191	76
	B	150	107	71

MONS 203908

Table 4. Survival and growth of newly hatched *Jordanella floridae* after 40 days' exposure to Aroclor 1248

Mean measured concentration (µg/liter)	Initial number of animals	Mean survival (%)	Final mean weight (g)	Final mean length (mm)
18	20	0	—	—
5.1	20	35	.60	21.8
2.2	20	85	3.02	24.1
0.54	20	100	4.47	26.3
0.18	20	90	3.90	25.5
0 (control)	20	100	4.33	24.6

MONS 203909

Table 5. Terminal residues of Aroclor 1242 in fathead minnows exposed for 8.5 months.

Mean measured PCB concentration (µg/liter)	Residues (µg/g)						Concentration factor	
	A		B		Mean			
	Males	Females	Males	Females	Males	Females	Males	Females
0.86	62(2)	92(3)[a]	—	—	236	92[c]	274,000	107,000
	410[4][b]	—	—	—				
2.9	—	—	124(3)	98(3)	93	107	32,000	37,000
	—	—	62[5]	117[5]				
5.4	306(1)	364(2)	—	436(2)	345	436	63,000	81,000
	278[2]	430[4]	452[2]	514[5]				

[a]Mean of (N) individual samples.
[b]Pooled samples of [N] fish.
[c]Average of pooled and mean individual analysis for both A and B tests.

MONS 203910

Table 6. Terminal residues of Aroclor 1254 in fathead minnows exposed for 8 months

Mean measured PCB concentration (µg/liter)	Residues (µg/g) A Males	A Females	B Males	B Females	Mean Males	Mean Females	Concentration factor Males	Concentration factor Females
0.23	57(2)	28(1)	43(2)[a]	—	54	45[c]	235,000	196,000
	—	48[6]	61[4][b]	60[4]				
0.52	133(2)	99(3)	64(2)	104(2)	81	105	156,000	201,000
	54[3]	—	74[4]	113[5]				
1.8	204(1)	458(3)	103(1)	361(2)	196	429	109,000	238,000
	83[2]	347[6]	394[4]	553[5]				
4.6	803(1)	741(1)	1110(1)	1004(5)	1036	999	225,000	217,000
	1204[3]	1253[3]	—	—				

[a] Mean of (N) individual samples.
[b] Pooled samples of [N] fish.
[c] Average of pooled and mean individual analysis for both A and B tests.

MONS 203911

Table 7. Terminal residues in control fish from Aroclor 1242 study

Fish (µg/g)	P,P'-DDE	Aroclor 1248	Aroclor 1260
A controls			
Males (1)[a]	0.02	--	2.2
Females (8)	0.08	3.3	2.8
B controls			
Males (3)	0.04	0.9	1.1
Females (6)	0.10	3.2	2.8

[a]Average of (N) fish.

MONS 203912

Table 8. Terminal residues in control fish from Aroclor 1254 study

Fish (ug/g)	p',p'-DDE	Aroclor 1248	Aroclor 1260
A controls			
Males (3)[a]	0.05	0.7	1.1
Females (6)	0.04	1.1	2.3
B controls			
Males (2)	0.03	0.9	1.9
Females (8)	0.04	1.6	2.7

[a]Average of (N) fish.

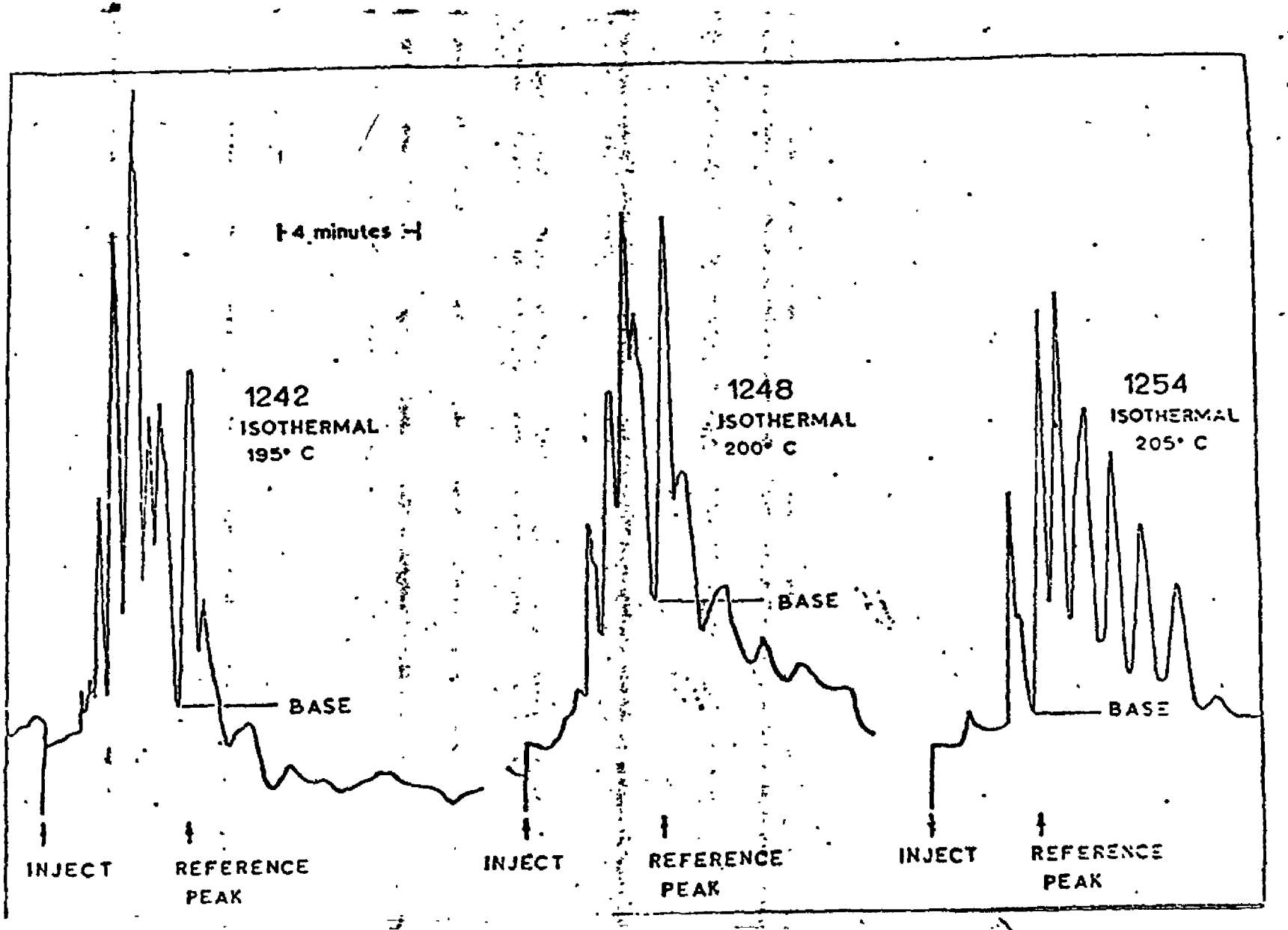
MONS 203913

Table 9. Residues in feed used in tests

	Pesticide and PCB (ug/g)				
	p,p'-DDE	p,p'-DDD	p,p'-DDT	Aroclor 1248	Aroclor 1254
Fish food Jan., 1971	0.22	0.02	0.10	0.3	0.8
Fish food Feb., 1971	0.20	0.02	0.10	0.5	1.5

MONS 203914

Figure 3. Single peak used as reference for quantitation of Aroclors 1242, 1248, 1254.



Nebeker, Puglisi and DeFoe

Org in Gulf Fisheries

Biological Studies on PCBs

Acute toxicity to fish The toxicity of the Aroclor® series was determined using the standard 96-hr static bioassay and cutthroat trout. Additional tests were also made with bluegills and channel catfish (Table 1). The solubilities of the Aroclor® formulations in water are reported in the range of 0.1-0.3 µg/l.

The results of these tests indicate a decrease in acute toxicity for Aroclor® 1254 and higher. The PCB toxicity indicated by these tests is misleading in that most fish mortalities occurred in the last 24 hours of the test and the concentrations of the test solutions were considerably above the true solubilities. The toxicities of these compounds became more apparent in long term, intermittent-flow bioassays.

The acute oral toxicity of Aroclor® 1242 and 1260 to rainbow trout was greater than 1500 mg/kg (given *per os* for 5 days at 300 mg/kg/day).

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MONS 203917

Table 1. Acute toxicity[1] of several Aroclors® to selected fishes.

Aroclor®	Species	Temperature (C)	96-hr TL_{50} (ug/l)
1221	Cutthroat trout	8.9[2]	1,170
1232	" "	8.9	2,500
1242	" "	8.9	5,430
1248	" "	8.9	5,750
1254	" "	8.9	42,500
1260	" "	8.9	60,900
1262	" "	8.9	> 50,000
1268	" "	8.9	> 50,000
4465	" "	8.9	> 50,000
5442	" "	8.9	> 50,000
5460	" "	8.9	> 50,000
1248	Channel catfish	18.3[3]	6,000
1254	" "	18.3	12,000
1248	Bluegills	18.3[3]	278
1254	"	18.3	2,740

1/ Static bioassay

2/ Alkalinity, 159 ppm; pH 7.6

3/ Alkalinity, 35 ppm; pH 7.1

Chronic toxicity to fish Intermittent-flow tests were conducted with rainbow trout, channel catfish, bluegills, and yellow perch and Aroclors® 1242, 1248, 1254 and 1260. Rainbow trout were the most susceptible to the Aroclor® compounds, then yellow perch, bluegills, and channel catfish (Table 2). Aroclor® 1248 was the most toxic to all species tested. Aroclor® 1242 was equal or perhaps slightly more toxic than 1254. The test with yellow perch and 1248 serves as a model for estimating time-independent toxicity (Figure 1).

Table 2. Toxicity of four Aroclors® and DDT to four species of fish in dynamic exposures.

Species	Compound	TL_{50}s (ppb) after 5 to 35 days						
		5	10	15	20	25	30	35
Rainbow trout	DDT	4.2	1.4	0.5 (0.3-0.9)	0.4	0.2	-	-
	Aroclor 1242	67	48	18 (11-31)	10	12	-	-
	Aroclor 1248	54	38	16 (9-31)	6.4	3.4	-	-
	Aroclor 1254	-	160	64 (29-140)	39	27	-	-
	Aroclor 1260	232	326	143 (33-610)	78	49	51	-
Channel catfish	DDT	-	-	2.3	1.3	0.86	0.57 (0.28-1.1)	-
	Aroclor 1242	-	125	219	150	132	87 (46-164)	
	Aroclor 1248	-	121	121	115	104	75 (29-197)	-
	Aroclor 1254	-	303	286	293	181	139 (94-349)	-
	Aroclor 1260	-	535	482	512	465	433 (185-1010)	-
ucpills	DDT	1.2	1.4	1.6	1.3	0.59 (0.39-0.89)	0.35 (0.21-0.58)	-
	Aroclor 1242	-	-	164	125	120	84 (48-150)	-
	Aroclor 1248	136	115	111	106	100	78 (42-143)	-
	Aroclor 1254	-	-	303	260	239	177 (97-321)	-
	Aroclor 1260	-	-	-	-	-	-	-

MONS 203920

Table 2. Continued

Species	Compound	TL_{50}s (ppb) after 5 to 35 days						
		5	10	15	20	25	30	35
Yellow perch	Aroclor 1242	-	-	-	135	94 (78-114)	92	-
	Aroclor 1248	-	-	110	90	78	72 (58-88)	-
	Aroclor 1254	-	-	128	92	92	92 (76-110)	-
	Aroclor 1260	-	-	-	-	-	240	185 (139-247

Water: pH = 7.4, alkalinity=237 ppm, hardness=272 ppm, and 17° C.
No value means insufficient data for computation of TL_{50}.

MONS 203921

AROCLOR® 1248 - YELLOW PERCH

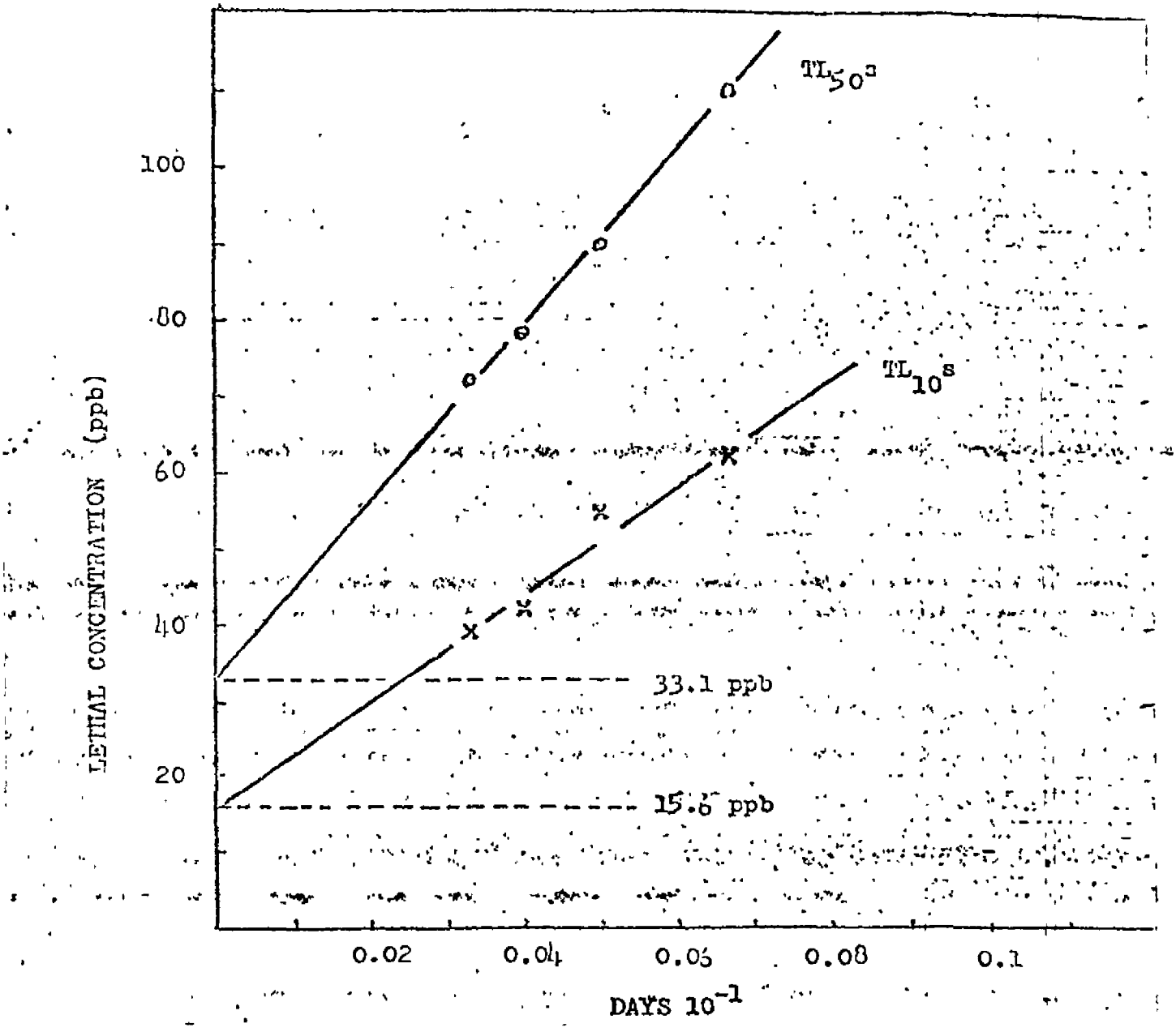

Figure 1. Estimation of time-independent toxicity by intermittent-flow bioassay.

Toxicity to Invertebrates Static and continuous-flow tests with invertebrates did not differ as much as those with fish. In general, insects were much more resistant to the Aroclors® than were crustacea (Table 3). Scud (Gammarus fasciatus) were also exposed to Aroclor® 1254 for 7 days in an intermittent-flow diluter at 17° C and the TL_{50} value was 34 µg/l (24-45). Homologues having lower chlorine numbers were more toxic to scud than those having higher chlorine numbers (Table 4).

Bioconcentration by aquatic microorganisms Aroclors®, like some of the organochlorine insecticides, appear to be rapidly and greatly concentrated by various organisms. For example, preliminary experiments showed that Daphnia magna concentrated ^{36}Cl-Aroclor® 1254 by 45,000 times after only 48 hours of exposure to a concentration of 300 ng/l. These data closely parallel that obtained in DDT and aldrin investigations with Daphnia magna.

Bioconcentration by aquatic invertebrates The potential of 1254 to accumulate in fish-food organisms was investigated by exposing several species of aquatic invertebrates to a ^{36}Cl-labeled formulation of this chemical in a continuous-flow system. All invertebrates exposed to 1254 showed an initial period of rapid uptake and residue magnification many times greater than the concentrations in water. For example, late instar mosquito larvae Culex tarsalis exposed to 1.5 µg/l of 1254 accumulated a residue of 19 mg/kg within 24 hours. This represents a 12,600-fold increase over the residues in water. The tissue residues continued to accumulate until the seventh day when the mosquito larvae transformed into pupae.

Table 3. Aroclor® and DDT toxicity to invertebrates.

Compound	Organism[1/]	Bioassay type[2/]	Exposure (days)	TL_{50} (ug/l)
Aroclor® 1242	Crayfish	static	7	30
Aroclor® 1254	Crayfish	static	7	100
Aroclor® 1254	Crayfish	continuous-flow	7	80
DDT	Crayfish	static	4	100
Aroclor® 1242	Scud	continuous-flow	4	10
Aroclor® 1242	Scud	continuous-flow	10	5.0
Aroclor® 1248	Scud	static	4	52
Aroclor® 1254	Scud	static	4	2,400
DDT	Scud	static	4	3.2
DDT	Scud	continuous-flow	5	0.6
Aroclor® 1254	Glass shrimp	continuous-flow	7	3.0
DDT	Glass shrimp	static	5	1.0
DDT	Glass shrimp	continuous-flow	5	1.3
Aroclor® 1242	Dragonfly	static	7	800
Aroclor® 1254	Dragonfly	static	7	1,000
Aroclor® 1242	Damselfly	continuous-flow	4	400
Aroclor® 1254	Damselfly	continuous-flow	4	200
DDT	Damselfly	static	4	56

1/ Crayfish (*Orconectes nais*), Scud (*Garmarus fasciatus*), Glass shrimp (*Palaemonetes kadiakensis*), Dragonfly (*Macronia* sp.), Damselfly (*Ischnura verticalis*).

2/ Temperature, 15.6° C; alkalinity, 35 ppm; pH, 7.1

MONS 203924

Table 4. Toxicity[1/] of five PCB homologues to scud[2/] at 21 C.

PCB isomer	TL_{50} (mg/l) and 95% confidence intervals at -- 24 hr	96 hr
2,3,4' trichlorobiphenyl	0.10 (0.08-0.14)	0.07 (0.05-0.12)
4,4' dichlorobiphenyl	0.16 (0.11-0.23)	0.10 (0.06-0.15)
2,4' dichlorobiphenyl	0.15 (0.10-0.20)	0.12 (0.08-0.18)
2,4,6,2', 4', 5' hexachlorobiphenyl	0.20 (0.16-0.26)	0.15 (0.09-0.21)
2,4,5,2', 5' pentachlorobiphenyl	0.43 (0.38-0.50)	0.21 (0.12-0.36)

[1/] Static bioassay.

[2/] Gammarus pseudolimnaeus.

MONS 203925

In some tests, we were able to continue the exposure until an apparent plateau or equilibrium concentration was reached within the organism. For example, scud were exposed continuously to 1.6 µg/l of 1254 in water until residues reached an apparent equilibrium concentration at 14 days; total body residues at this time were 38 mg/kg, a concentration 27,000 times that in water. Once this equilibrium was reached within the organism, no further residue magnification was recorded after an additional 21 days of exposure (Figure 2). Waterfleas accumulated a residue 30,000 times the water concentration (1.1 µg/l) in 3 days. In a similar study early instar crayfish Orconectes nais exposed to 1.2 µg/l of 1254 accumulated residues at a slower rate. The crayfish were accumulating 1254 at a linear rate after 28 days of exposure when the experiment was terminated (Figure 3).

Scud exposed to 1254 were analyzed by gas-liquid chromatography to investigate potential shifts in the residue composition which may have occurred as a result of metabolism. However, we found no significant alterations in the chemical, but some isomers were accumulated more than others. The most notable shift of residue components was a two-fold increase in concentrations of the lower chlorine isomers (tri- and tetrachlorobiphenyl isomers). The relative concentration of higher chlorinated isomers (penta- and hexachloro biphenyls) were decreased by one half.

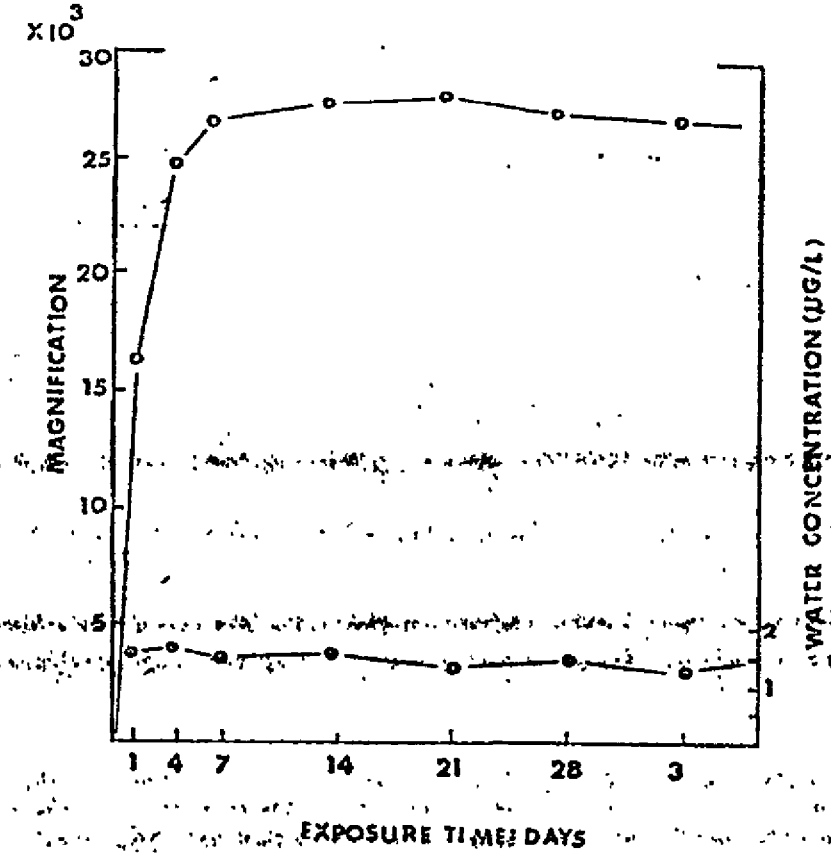

Figure 2. Biological magnification by scud, Gammarus pseudolimnaeus of ^{36}Cl-Aroclor® 1254 from water during 35 days exposure.

MONS 203927

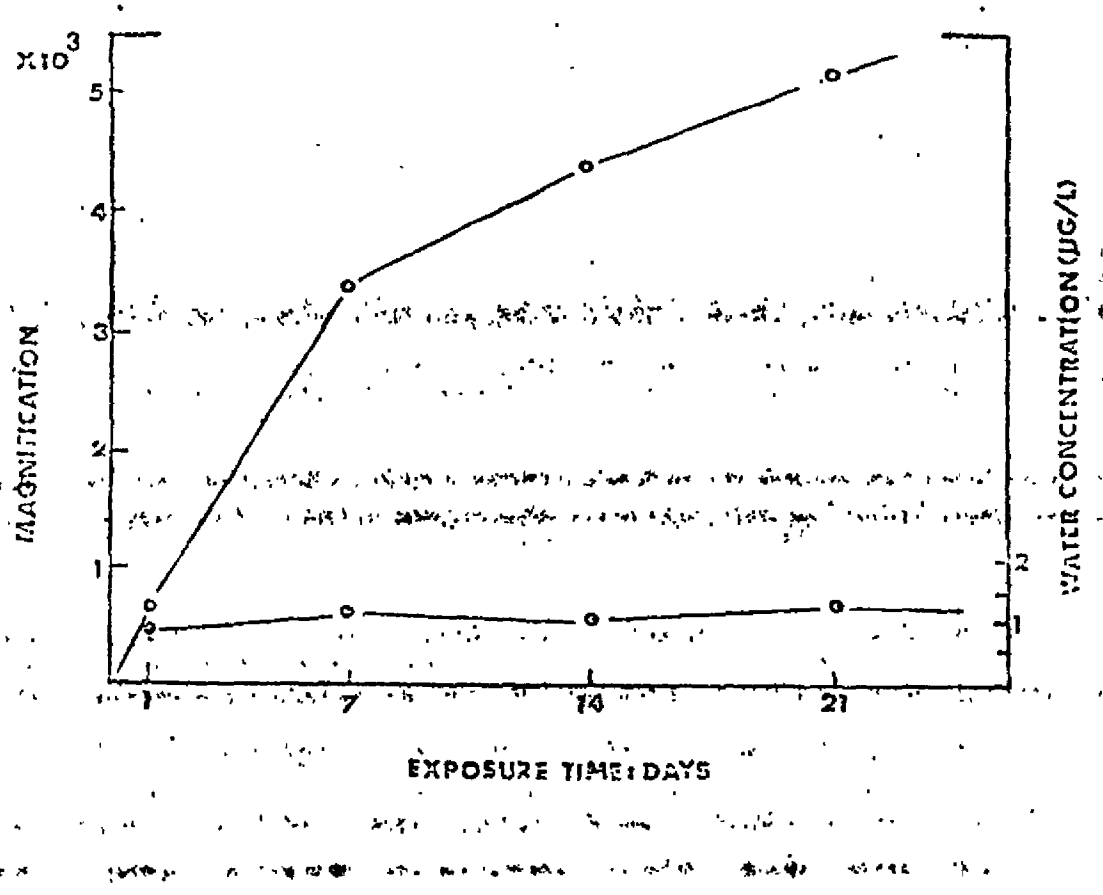

Figure 3. Biological magnification by crayfish Orconectes nais of ^{36}Cl-Aroclor® 1254 from water during 21 days of exposure.

MONS 203928

Physiologic effects of PCBs Because the thyroid plays an integral role in reproduction, osmoregulation, and oxidative metabolism, we studied its activity in five species of fish exposed to organochlorine chemicals by diet or bath. Aroclors® 1248 and 1254 had significant effects on thyroid activity (72-hr ^{125}I-uptake) (Table 5). The lowest dietary concentrations that affected thyroid activity were 0.48 µg/gm (ppm in dry food) of Aroclor® 1254. These concentrations are comparable to those found in natural fish foods.

MONS 203929

Table 5. Thyroid activities in five species of fish exposed to polychlorinated biphenyls (PCBs) or DDT.

Chemical	Dosage (ug/kg bw/day)	Concentration (ppm)	Species	Exposure (days)	Changes in thyroid activity[1]	Whole body residue[2]
Aroclor 1232	40	1.2	Channel Catfish	160	NC	3.7
Aroclor 1232	400	12	Channel Catfish	160	NC	8.3
Aroclor 1248	40	1.2	" "	160	NC	4.2
Aroclor 1248	400	12	" "	160	NC	14.0
Aroclor 1254	40	1.2	" "	160	+56	5.4
Aroclor 1254	400	12	" "	160	+91	21.0
Aroclor 1260	40	1.2	" "	160	NC	5.5
Aroclor 1260	400	12	" "	160	NC	45.0
Aroclor 1254	1.45	0.05	Coho salmon	260	NC	0.40
Aroclor 1254	14.5	0.48	" "	260	+52	0.59
Aroclor 1254	145	4.8	" "	260	+35	3.87
Aroclor 1254	1450	48	" "	260	+87	54.5
Aroclor 1254	14,500	480	" "	260	+119	646.0

MONS 203930

Table 5. Continued.

Chemical	Dosage (ug/kg bw/day)	Concentration (ppm)	Species	Exposure (days)	Changes in thyroid activity[1/]	Whole body residue[2/]
Aroclor 1248	-	4	Bluegills	74	NC	NA
Aroclor 1248	-	7.3	" "	74	-29	NA
Aroclor 1254	-	4.6	" "	74	NC	NA
Aroclor 1254	-	7.5	" "	74	+54	NA
Aroclor 1248	-	6.7	Channel catfish	77	+50	NA
Aroclor 1248	-	11.8	" "	77	+50	NA
Aroclor 1254	-	3.5	" "	77	+44	NA
Aroclor 1254	-	5.3	" "	77	+105	NA

1/ Percent change in 72-hr ^{125}I-uptake from controls; NC = no significant difference.

2/ NA = not analyzed; residue concentration = ug/g of wet body weight.

MONS 203931

Growth of lake trout was retarded by Aroclor® 1248 in the diet for 3 months. Concentrations of 1.2, 3.8, and 12 ppm decreased weight gain by 6, 10, and 28%, respectively, below that of controls. Growth of the high-exposure group was only about half that of the controls after 6 months. Conversely, thyroid activity, as indicated by 72-hr radioiodine uptake, was stimulated by PCB exposure (Figure 4). Serum cortisol concentrations ranged from 33 to 46% below that of the controls. Depressed growth rates and elevated thyroid activity imply metabolic inefficiency producing a "loading" stress that can adversely affect viability and reproductive success.

MONS 203932

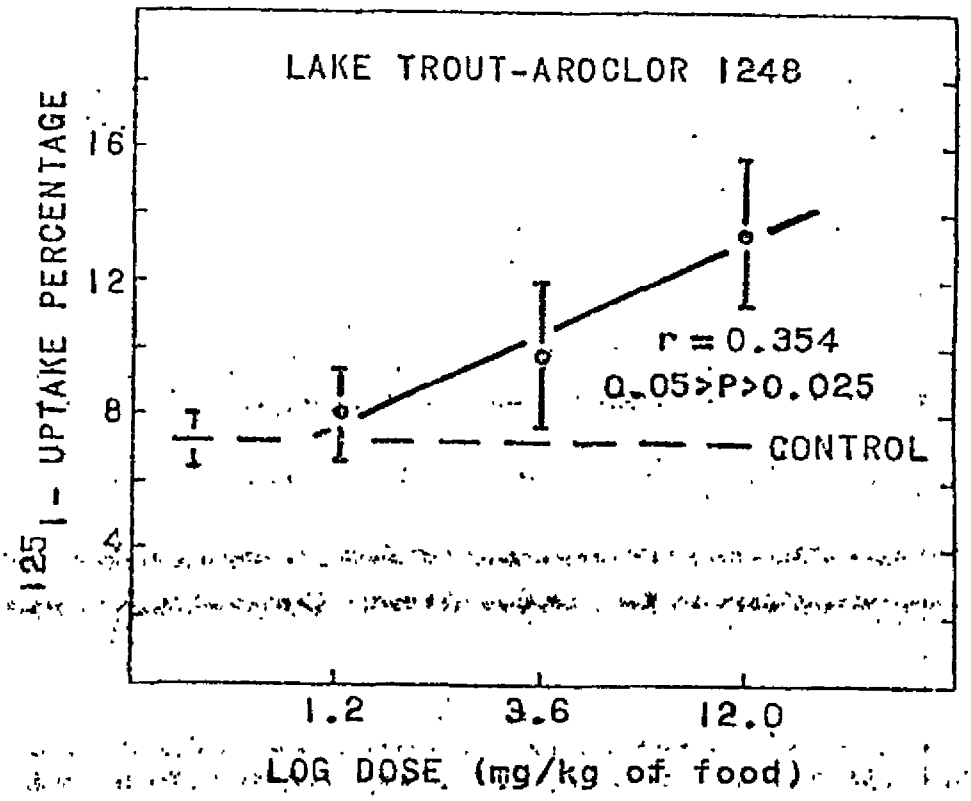

Figure 4. Thyroid stimulation by 6 month dietary exposure to Aroclor® 1248.

Chronic dietary toxicity of PCBs

Aroclor® 1248 was incorporated in diets of juvenile lake trout at concentrations of 0.1, 1.8 and 6.0 mg/kg of food (concentrations comparable to those found in natural foods). These concentrations depressed growth and serum cortisol levels, but stimulated thyroid activity during the first 160 days of the experiment (Table 6a). After 320 days, however, there were few differences between control and treated fish.

Dose-dependent pathologic changes were observed in the gills and livers of PCB-dosed fish. Gill lesions consisted of hyperplasia and hypertrophy of the respiratory epithelium and edema and intercapillary congestion of the lamellae. Changes in the liver included parenchymal degeneration, cytoplasmic vacuolization of the hepatic cells, and pleomorphism of the liver cells.

Whole-body residues increased during the exposure (Table 6b), but after the trout were fed uncontaminated food for 60 days, residues declined an average of 31%, 15%, and 12% in the 0.6-, 1.8-, and 6.0-mg/kg lots, respectively.

Also, lake trout growth was retarded by dietary Aroclor® 1248 and chlordane in combination. Fish that consumed food containing 0.94 µg/g of Aroclor® 1248 and 0.26 µg/g chlordane for 80 days grew 15% less than the controls.

Table 6a. Growth, serum cortisol concentrations, and thyroid activity in juvenile lake trout exposed by feed to Aroclor® 1248.

	Percent growth			Serum cortisol		Thyroid activity	
	160 days	310 days	total growth	160 days	320 days	160 days	320 days
Control	887	2,930	3,817	6.5±0.8	10.3±0.6	3.6±0.4	1.2±0.2
0.6 mg/kg	708	3,017	3,724	3.9±0.4	7.8±1.4	4.0±0.7	1.3±0.1
1.8 mg/kg	777	3,032	3,810	4.3±0.8	11.2±1.4	4.9±1.1	1.2±0.1
6.0 mg/kg	522	3,262	3,783	3.5±0.2	13.7±1.3	6.7±1.1	1.0±0.1

Table 6b. Whole body residues (µg/g) in juvenile lake trout fed Aroclor® 1243.

Exposure (days)	Doses (mg/kg of dry food)			
	0	0.6	1.8	6.0
0	0.17	0.17	0.17	0.17
70	0.11	0.26	0.59	2.00
145	0.09	0.42	1.20	3.70
246	0.15	0.81	2.40	6.80
320	0.13	1.60	2.70	9.70
Recovery[1/]				
60	0.12	1.10	2.30	8.50

1/ Fed non-contaminated food.

half-life

MONS 203935

Uptake of dietary PCBs

Dietary doses of 1.45, 14.5, 145, 1,450, and 14,500 µg Aroclor® 1254/kg body wt. per day to coho salmon had no effect on growth, nor produced observable toxicosis until death occurred in the highest dosage group after 260 days. The two highest dosage groups achieved extremely high concentrations of residues (Table 7). Fish fed 14,500 µg/kg began dying on the 260th day, and 5 days later all fish had died. Thyroid activity was increased significantly after 260 days of treatment (Table 5). A detectable stimulation of thyroid activity occurred in salmon dosed with 1/1000th of that causing mortality.

Dietary doses of Aroclors® 1232, 1248, 1254, and 1260 to channel catfish at concentrations of 2.4 and 24 mg/kg (dry wt) caused no mortality nor had any effect on growth. Thyroid activity was altered significantly only by Aroclor® 1254. The low dose increased uptake by 56%, whereas a 91% increase was induced by the high dose. Residue accumulation was greatest in the groups exposed to the high dose of Aroclor® 1260; i.e., as the percent chlorine content of the PCB molecule increased, residue accumulation increased (Table 8).

Table 7. Whole body residues of Aroclor® 1254 (PCB) in coho salmon exposed to dietary concentrations of Aroclor® 1254 at 18° C.

Exposure (days)	PCB residues[1] (µg/g) after exposure to theoretical dietary dosages[2] (µg/kg body wt per day) of --					
	0	1.45	14.5	145	1,450	14,500
14	0.15	0.19	0.28	0.96	8.9	81.7
28	0.15	0.23	0.42	1.32	11.4	114.5
56	0.12	0.18	0.69	2.90	21.8	300.0
112	0.17	0.47	0.50	3.83	21.6	384.0
142	0.16	0.35	0.61	3.52	34.18	361.0
200	0.14	0.36	0.68	2.48	57.14	659.0
260	0.17	0.40	0.59	3.87	54.5	645.5

1/ Pooled samples of four fish.

2/ Dosage corresponds to 0.19 (background in feed), 0.25, 0.64, 6.4, 64, and 640 µg/gm food dry wt., respectively.

MONS 203937

Table 8. Whole body residues of Aroclors® 1232, 1248, 1254, and 1260 in channel catfish after 193 days exposure to dietary concentrations of the PCBs at 25° C.

Aroclor	Dosage[1] (µg/kg bw/day)	Exposure (Days) 17	45	87	150	193
1232	480	9.0[2]	5.4	5.2	11.3	14.5
1232	48	0.8	1.9	1.7	4.5	3.2
1248	480	13.0	2.3	4.3	NA	13.0
1248	48	0.6	0.9	1.3	NA	1.9
1254	480	10.0	0.8	0.8	14.2	21.0
1254	48	0.8	0.03	0.2	2.3	4.8
1260	480	6.2	5.0	7.5	17.0	32.0
1260	48	0.7	1.2	1.7	2.3	3.5

[1] Dosages of 480 and 48 µg/kg body wt. per day corresponds to 24 and 2.4 µg/gm food (dry wt.), respectively.

[2] Mean of three samples (µg/gm).

MONS 203938

Uptake of PCBs from water by fish

After 77 days, bluegills and channel catfish exposed to two concentrations of Aroclors® 1248 and 1254 in intermittent-flow diluters, magnified the Aroclors® by a factor of 20,000 to 60,000. Although the mean Aroclor® residue in the fish seemed dependent on water concentration, the magnification factor from water did not. For example, bluegills exposed to 2.6 and 7.3 µg/l of Aroclor® 1254 in water magnified those concentrations by 26,560- and 26,300-times and contained mean residues of 68.3 and 192 µg/g of whole fish, respectively.

Chromatograms of Aroclor® residues in bluegills and catfish showed a difference in storage rates for various Aroclor® components. Uptake appeared biased toward the later eluting components from the GC. After Aroclor® exposure was terminated, PCB elimination by fish was more rapid for the early eluting components.

MAY 28 1974

(28)

Effect of Polychlorinated Biphenyls (PCB's) on Survival and Reproduction of *Daphnia*, *Gammarus*, and *Tanytarsus*

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Trans. Amer. Fish. Soc. 103(4): Oct., 1974

MONS 203940

Abstract

Continuous-flow and static bioassays were conducted at 18 C, with survival and reproduction as measures of relative toxicity of eight PCB's, Aroclor 1221 (A-1221), A-1232, A-1242, A-1248, A-1254, A-1260, A-1262, and A-1268. Three PCB-mixture bioassays were also conducted. Aroclor 1248 was the most toxic to Daphnia magna of the eight Aroclors tested in static tests; the 3-wk LC50 was 25 µg/liter. Aroclor 1254 was the most toxic PCB to Daphnia under continuous-flow conditions with a 3-wk LC50 of 1.3 µg/liter. Ninety-six-hr LC50 values for A-1242, and A-1248 on Gammarus pseudolimnaeus in continuous-flow tests were 73 and 20 µg/liter. Survival after 60 days was 52% at 8.7 µg/liter 1242 and 53% at 5.1 µg/liter A-1248. Reproduction and survival of young were good at 2.8 µg/liter A-1242 and 2.2 µg/liter A-1248. The midge Tanytarsus dissimilis, in continuous-flow tests, did not emerge in abundance above 5.1 µg/liter A-1248 or 3.5 µg/liter A-1254. The 3-wk LC50 for Aroclor 1254 was 0.65 µg/liter for larvae and 0.45 µg/liter for pupae. Tissue residues in Gammarus pseudolimnaeus ranged from 4.0 µg/gram A-1254 in control animals to 552 µg/gram A-1248 in scuds held for 60 days in water containing 5.1 µg/liter A-1248.

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Introduction

Polychlorinated biphenyls (PCB's) are widespread in the environment, rivaling DDT in general occurrence (Risebrough and Bodine 1970). Their significance in the aquatic environment as toxicants is now being revealed. Duke, Lowe, and Wilson (1970) have documented the occurence of one of the many PCB mixtures (Aroclor 1254) in the water, sediment, and biota of Escambia Bay, Florida. Veith and Lee (1970) reviewed chlorinated biphenyl contamination in natural waters and stated that PCB's may be among the more widespread contaminants. A general review of the structural and physical properties, uses, analytical methods of analysis, concentrations found in nature, and toxicology of PCB's is given by Peakall and Linear (1970). The acute toxicity of some of the many types of PCB's produced commercially (Monsanto Chemical Co.) has been demonstrated for a few species of fish and fish-food organisms (Stalling 1970; Zitco 1970; Nebeker, Puglisi, and DeFoe 1972; Duke, personal communication).

To assess the danger of the compounds to fish-food organisms, bioassays were designed and conducted with Daphnia magna as the initial test animal. All eight commercially available PCB's-Aroclor 1221 (A-1221) A-1232, A-1242, A-1248, A-1254, A-1260, A-1262, and A-1268—were tested. Seven continuous-flow bioassays were carried out with Aroclor 1248 and A-1254, twenty-four 3-wk static bioassays with all eight Aroclors, and three bioassays with PCB mixtures. Survival and reproductive success of Daphnia magna were used as measures of toxicity. The effects of A-1242 and A-1248 on the growth, survival, and reproduction of

Gammarus pseudolimnaeus and the effects of A-1248 and A-1254 on the growth, survival, and adult emergence of Tanytarsus dissimilis were also determined. Tissue residues were also determined in Gammarus to measure uptake of PCB's.

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Materials and Methods

Physical Testing Methods

Daphnia static tests—Test containers were 250-ml glass beakers which were randomly distributed and covered with glass sheets to minimize evaporation. The experiments were conducted at 18 ± 1 C; the photoperiod was set for 16 hours light per day. Raw Lake Superior water was used for all testing.

Daphnia continuous-flow tests—*Daphnia*, *Gammarus*, and *Tanytarsus* were tested in a continuous-flow system which consisted of 24 stainless steel and glass 7.6 liter (2-gal) aquaria and which permitted the testing of five concentrations and a control in quadruplicate. A proportional diluter (Mount and Brungs 1967) provided the necessary continuous-flow conditions. A gas syringe filled with acetone and PCB was used with the diluter system to deliver the toxicant to the mixing chamber of the diluter. Additional agitation was maintained by circulating the mixing-chamber contents through a submersible pump. Mixing boxes with four-way splits to the test aquaria provided further mixing of the PCB solutions. All tanks were randomly distributed on the test tables. Raw Lake Superior water was used for all testing. The diluter delivered 150 ml to each test tank every 3 minutes. This flow rate ensured adequate dissolved oxygen levels, replenishment of fresh toxic solutions, and a complete exchange of water in the test tanks every 4-5 hours.

Test temperatures were maintained at 18 ± 1 C. Duro-test[2] (Optima FS) and wide spectrum Grow-lux fluorescent tubes provided light for all

[2]Mention of commercial products does not constitute endorsement by the U. S. Environmental Protection Agency.

tests. The photoperiod of Evansville, Indiana, was maintained during testing, and adjustments in day length were made every 2 wks, as recommended by the Bioassay Methods Committee, National Water Quality Laboratory (Bioassay Committee MS 1971).

Biological Testing Methods

Daphnia static tests (single PCB)—Daphnia magna, obtained from the National Water Quality Laboratory cultures, were tested from young stages less than 24 hrs old through maturation, reproduction, and growth of their young (3 wks). Five animals were placed in a 250-ml beaker containing 200 ml of test solution; four duplicates gave 20 test animals at each concentration. The survival of the original animals was recorded each week, and the test solutions were renewed. The young surviving after 2 wks were counted and discarded. Young surviving after the third week were also counted, and the total number of young surviving was recorded. All tests were repeated three times.

The 3-wk LC50, that concentration at which 50% of the animals had died after 3 wks, was used as one measure of toxicity. Fifty percent and 16% reproductive impairment were used as measures of reproductive success (Biesinger and Christensen 1972). These values describe the survival of young as the percentage decrease from the highest number of young produced in either the control or one of the lower tested toxicant concentrations. The LC50, 50% and 16% reproductive impairment values, and 95% confidence limits for each were determined by the statistical method of Litchfield and Wilcoxon (1949). The terminology recommended by Sprague (1969) was used to present toxicity data.

Food for the Daphnia was prepared from 0.5 g powdered dried wheat leaves and 10 g enriched trout food (fry granules) mixed in a blender with 300 ml of Lake Superior water (Biesinger and Christensen 1972).

Daphnia static mixture tests—Different percentages of a mixture of all eight PCB's were tested to determine the percentage survival in an aquatic system containing all the PCB's at low concentrations which barely permit reproduction. Testing methods were the same as those used in previous Daphnia static tests, and 50% survival and 50% and 16% reproductive impairment were also calculated as previously. The mixture consisted of the following concentrations (in µg/liter:) A-1221, 89; A-1232, 53; A-1242, 48; A-1248, 16; A-1254, 18; A-1260, 22; A-1262, 24; and A-1268, 162.

Daphnia continuous-flow tests—Five animals, less than 24 hrs old, were placed into 7.6 liter (2-gal) aquaria; four aquaria gave 20 test animals at each concentration. All surviving original Daphnia and their young were counted at the end of each 2- or 3-wk test. Analysis of data and physical-chemical conditions were the same as for the static tests; however, the animals were fed finely powdered fish food twice a day rather than the solution used in static tests. Mean measured PCB concentrations from the continuous-flow test tanks were used for all calculations.

Gammarus continuous-flow tests—Juvenile scuds, Gammarus pseudolimnaeus, from the Eau Claire River (Wisconsin) were held in the laboratory for at least 1 wk prior to testing. Twenty animals were placed in each tank; two (A-1242 test) and three (A-1248 test) replicate

tanks for each PCB concentration gave 40 (A-1242) and 60 (A-1248) scuds in each concentration. They were fed a combination of well-soaked maple and aspen leaves; dry commercial fish food; and algae, which were permitted to grow on the tanks before introduction of the test animals. Tests were maintained for 2 mo; they were started with juvenile scuds and were continued until the animals matured, coupled, and reproduced (1 mo). Reproduction was allowed to continue for 1 mo before the test was ended. The adults were counted, and the young were counted and weighed.

Midge continuous-flow tests—The species used was Tanytarsus (Paratanytarsus) dissimilis; its original source is unknown. It was tested with Daphnia as they are compatible. The midges were reared in extra tanks in the room so that many egg-carrying females were flying in the room at the beginning of the test. These females deposited eggs in all clean test tanks when the test was started, prior to introduction of Daphnia, and within a few hours all tanks contained larvae. This continuing random ovipositing provided an abundant supply of young midges, which lived in cases on the bottom of the aquaria, independent of the Daphnia. The occurrence of mature larval midge cases and pupal cases, which the growing larvae constructed, was used as one measure of growth and survival. The additional occurrence of pupae and cast pupal skins at the water surface indicated the success of adult emergence.

All mature larval and pupal cases were counted at the end of 3 wks. Tanks were observed daily to determine when successful adult emergence occurred. The 3-wk LC50 was based on 50% reduction of test animals, with the number of control midges being considered as 100%. This

procedure was useful under the particular conditions of these tests, but it is not recommended as a routine method.

Analytical Methods

Static Daphnia tests—Test solutions were prepared by weighing the Aroclor samples on an analytical balance and transferring them to volumetric flasks with acetone and Triton X-100, a surfactant (maintained at 0.03 x PCB level) added to help keep the PCB's solution. The concentrations of acetone and Triton X-100 used were tested previously and found to be nontoxic at the levels used during testing. The Triton-PCB mixtures were diluted to 500 ml with acetone and used as stock solutions. Portions of each stock solution were diluted with acetone to give five different working stock solutions for each Aroclor. One ml of each stock solution and 1 ml of food suspension were pipetted into a volumetric flask and diluted to 1,000 ml with Lake Superior water. Control solutions were prepared with 1 ml of acetone and 1 ml of food suspension in a liter of lake water to keep the acetone concentration constant (1 ml/liter) in all test solutions.

Continuous-flow tests—Methodology for preparation of stock solutions, diluter delivery systems, and analysis of PCB concentrations (gas chromatography) was identical to that used in earlier studies by Nebeker, Puglisi, and DeFoe (in press) with fathead minnows.

Chemical characteristics of the Lake Superior test water were monitored daily or weekly, and measurements were made with methods described by the American Public Health Association (1965). Dissolved oxygen in the tanks was measured by the azide modification of the Winkler method. Chemical characteristics were: pH, 7.5-8.0; acidity, 2.4-4.0 mg/liter; alkalinity, 40-43 mg/liter (as $CaCO_3$); calcium hardness, 34-36 mg/liter; and total hardness, 44-46 mg/liter.

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A standard one/two factor analysis-of-variance program was used to test for experimental differences.

Terminal residues of Aroclor 1242 and A-1248 in Gammarus were determined by the Fish-Pesticide Laboratory, Columbia, Missouri, using the methods of Stalling and Johnson (1971). Residues of PCB's in feed used in tests were also determined (Table 1).

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Results and Discussion

Daphnia Static Tests

Of the PCB's tested A-1248 was the most toxic to Daphnia; the 3-wk LC50 was 25 µg/liter. Fifty percent reproductive impairment occurred at 24 µg/liter, and 16% impairment was at 16 µg/liter. The toxicity of the other PCB's decreased progressively from A-1248 to A-1221 and from A-1248 to A-1268 (Table 2). Aroclors A-1254, A-1260, and A-1262 were nearly as toxic as A-1248, and A-1242 and A-1232 were about half as toxic as A-1248. Aroclor-1221 was much less toxic; the LC50 was 180 µg/liter. The least toxic was A-1268, with an LC50 of 253 µg/liter. In all tests reproduction, as judged by the number of young produced, was impaired by lower concentrations of Aroclor than was required to cause death. Values for 50% reproductive impairment of all PCB's tested were lower than the LC50 for survival. Excepting A-1221 and A-1268 the confidence limits indicate that the values are not significantly different, however.

No survival or reproduction occurred at 40% of the PCB mixture after 3 wk. At 20% of the mixture there was 17% adult survival and 13% young survival (Table 3). Fifty percent of the adults survived at 15% of the mixture. Survival of young was reduced to 50% at 14% of the mixture, and 16% reproductive impairment occurred at 11% of the mixture. Good survival, growth, and reproduction occurred at and below 5% of the mixture.

Daphnia Continuous-Flow Tests

Aroclor-1254 was most toxic to Daphnia under continuous-flow test conditions. There was no significant difference between the 2-wk LC50 of 1.8 µg/liter and the 3-wk LC50 of 1.3 µg/liter (Table 2). Reproductive

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impairment occurred at or just below those concentrations that prevented survival of the adults. Aroclor-1248 killed 50% of the adult Daphnia at 2.6 µg/liter, and 50% of the young survived at 2.1 µg/liter. Sixteen percent reproductive impairment occurred at 1.0 µg/liter for A-1248 and for A-1254 at 0.48 (2 weeks) and 1.0 (3 weeks) µg/liter (Table 2). Almost no reproduction occurred at 7.5 µg/liter A-1248 (Table 4). No reproduction occurred at 3.8 µg/liter A-1254, and no adults survived 3.5 µg/liter. The number of young produced ranged from 0.7 young per initial adult in 7.5 µg/liter A-1248 to 76 young per surviving adult in 0.45 µg/liter A-1254 (Table 4). The Aroclors were much more toxic in continuous-flow conditions due to continual replacement of fresh PCB. Almost one-third of the PCB added to the test water was lost to the air, with some lost to bacteria, algae waste materials, test container surfaces, and test animal tissues. The difference between static- and continuous-flow results illustrates how critical test methodology can be for certain chemicals.

Gammarus Tests

Ninety-six-hr LC50 values for Gammarus juveniles were calculated for Aroclor-1242 and A-1248 (American Public Health Association 1965). Aroclor-1248 was twice as toxic as A-1242; the mean LC50 was 29 µg/liter for A-1248 (four tests, range 26-32 µg/liter) and 73 µg/liter for A-1242 (two tests, 72 and 74 µg/liter). Survival of the initial test animals after 2 mo was significantly less than survival after 96 hr (Tables 5 and 6). No live animals remained at 26 µg/liter A-1242 or 18 µg/liter A-1248. Fifty-two percent were alive at 8.7 µg/liter A-1242 (Table 5) and 53% were alive at 5.1 µg/liter A-1248 (Table 6). Good reproduction

occurred at 2.8 µg/liter A-1242 and 2.2 µg/liter A-1248. Some reproduction occurred at 5.1 µg/liter A-1248, but it was only half that of the control and only one-fourth that of 2.2 µg/liter (Table 6). Terminal residues of A-1242 and A-1248 in Gammarus exposed for 60 days are given in Table 7, with control animal residue data summarized in Table 8.

Midge Tests

Adult midges emerged at concentrations up to 9 µg/liter A-1248. Larvae were present at 18 µg/liter, but adult emergence did not occur. Abundant emergence did not occur above 5.1 µg/liter. Arbelor-1254 was more toxic to midges as no emergence occurred above 3.5 µg/liter, and abundant emergence did not occur above 3 µg/liter, even though larvae were present (Table 9). Survival and growth of the midge when tested with A-1254 were excellent in control chambers, but were reduced by 50% at the lowest test concentration of 0.45 µg/liter (Table 9). At 1.2 µg/liter the numbers of larval cases were reduced to 35% of the control, and the numbers of pupal cases were reduced to 18% of the control. No larval cases were formed at 33 µg/liter, and no pupal cases were constructed at 9 µg/liter. The calculated 3 wk LC50 for A-1254 (50% reduction based on control as 100%) was 0.65 µg/liter for larvae and 0.45 µg/liter for pupae, indicating that a safe level of A-1254 for midge well-being is below 1 µg/liter.

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We also thank Monsanto Chemical Company for their cooperation and for making Aroclor samples available for testing.

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Table 1. Residues in feed used in tests

	Pesticide and PCB (µg/gram)				
	p,p'-DDE	p,p'-DDD	p,p'-DDT	Aroclor 1248	Aroclor 1254
Fish food Jan., 1971	0.22	0.02	0.10	0.3	0.8
Fish food Feb., 1971	0.20	0.02	0.10	0.5	1.5

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Table 2. Calculated 2- and 3-wk LC50 and 16% reproductive impairment values for Daphnia magna subjected to Aroclor 1248 and Aroclor 1254 in continuous-flow conditions and eight Aroclors in static conditions at 18 ± 1 C

Aroclor (PCB)	3-wk LC50 (µg/liter)	Confidence limits (0.05)	Reproductive impairment (µg/liter) 50%	16%
		Static test conditions		
A-1221	180	158.0-205.0	125	89
A-1232	72	62.6-82.8	66	53
A-1242	67	55.4-81.0	63	48
A-1248	25	21.4-29.2	24	16
A-1254	31	25.8-37.2	28	18
A-1260	36	27.7-46.8	33	22
A-1262	43	37.0-49.9	41	24
A-1268	253	222.0-288.0	206	162
		Continuous-flow test conditions		
A-1248	2.6 (2-wk LC50)		2.1	1.0
A-1254	1.8 (2-wk LC50)		1.1	0.48
A-1254	1.3 (3-wk LC50)		1.3	1.0

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Table 3. Survival and reproduction of Daphnia magna after a 3 week exposure to various percentages of a PCB mixture of 16% impairment concentrations at 18 ± 1 C[a]

Percentage of mixture[b]	Initial number of animals	Adults alive at end of test			Mean survival of adults (%)	Total young produced			Mean young produced[c] (%)
		Test 1	Test 2	Test 3		Test 1	Test 2	Test 3	
40	20	0	0	0	0[d]	0	0	0	0[d]
20	20	2	8	0	17[d]	80	152	68	13[d]
10	20	16	20	20	93	554	792	631	87
5	20	18	20	20	97	690	795	804	100
1	20	14	19	19	87	425	670	668	77
0.5	20	15	20	20	92	566	871	701	94
0.0	20	17	18	20	92	688	757	836	99

[a]Concentrations of each Aroclor that permitted reproduction, but reduced it by 16%.

[b]Mixture consisted of the following concentrations (in µg/liter): A-1221, 89; A-1232, 53; A-1242, 48; A-1248, 16; A-1254, 18; A-1260, 22; A-1262, 24; and A-1268, 162.

[c]Percentage of the highest young produced in one of the lower tested toxicant levels (5%).

[d]Significantly different from the controls at the 0.05 level.

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Table 4. Survival and reproduction of Daphnia magna after 2 weeks' continuous-flow exposure to Aroclor 1248 and Aroclor 1254, and 3 weeks' exposure to Aroclor 1254

Mean measured concentration (µg/liter)	Initial number of animals	Total number of adults alive at end of test	Mean survival of adults (%)	Total young produced	Young produced[a] (%)	Young per initial adult	Young per surviving adult
1248 (2 wk)							
7.5	60	3	5	43	2.6	0.7	14
2.5	60	39	65	699	43	12	18
0.86	60	55	92	1441	88	24	26
0.26	60	52	87	1641	100	27	31
0.1	50	37	74	627	46	13	17
0.0	50	30	60	786	56	16	26
1254 (2 wk)							
9.0	20	0	0	0	0	0	0
3.8	20	0	0	0	0	0	0
1.7	20	12	60	239	36	12	20
0.92	15	14	93	269	53	18	19
0.37	15	12	80	504	100	34	42
0.0	15	8	53	290	58	19	36
1254 (3 wk)							
33.0	40	0	0	0	0	0	0
9.0	40	0	0	0	0	0	0
3.5	40	0	0	0	0	0	0
1.2	40	28	70	1583	76	39	56
0.45	35	24	69	1810	100	52	76
0.0	30	24	80	1154	74	38	48

[a]Percent decrease from the highest number of young produced in either the controls or one of the lower tested treatment levels.

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Table 5. Survival and reproduction of Gammarus pseudolimnaeus after 2 months' exposure to Aroclor 1242 in continuous-flow systems at 18 C

Mean measured concentration (µg/liter)	Initial number of animals	Total number of adults alive at end of test	Mean survival of adults (%)	Total young produced	Young per surviving adult
234	40	0	0	0	0
81	40	0	0	0	0
26	40	0	0	0	0
8.7	40	21	52	0	0
2.8	40	31	77	131	4.2
0.0	40	19	48	130	6.8

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Table 6. Survival and reproduction of Gammarus pseudolimnaeus after 2 month's exposure to Aroclor 1248

Mean measured concentration (ug/liter)	Initial number of animals	Total number of adults alive at end of test	Mean survival of adults (%)	Total young produced	Young per surviving adult	Total weight of young (mg)	Mean weight of each young scud (mg)
18	45	0	0	0	0	0	0
5.1	45	24	53	169	7.0	90	0.53
2.2	45	33	73	729	22.1	287	0.39
0.54	45	32	71	627	19.6	336	0.54
0.18	45	33	73	357	10.8	154	0.43
0.0	45	29	64	330	11.4	200	0.61

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Table 7. Terminal residues of Aroclor 1242 and Aroclor 1248 in Gammarus exposed for 60 days

Mean measured PCB concentration (µg/liter)	Residues (µg/gram) A	B	Mean	Concentration factor
A-1242				
2.8	71(14)[a]	80(17)	76	22,000
8.7	246(9)	387(10)	316	29,000
26	409(1)	—	409	14,000
A-1248				
0.18	9(33)	—	9	24,000
0.54	15(32)	—	15	14,000
2.2	127(33)	—	127	38,000
5.1	552(24)	—	552	55,000

[a]Mean of (N) individual samples.

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Table 8. Terminal residues in control Gammarus from Aroclor 1242 study

Gammarus	p,p'DDE (µg/gram)	Aroclor 1248 (µg/gram)	Aroclor 1254 (µg/gram)
A Controls	0.12(7)[a]	8.0	4.0
B Controls	0.06(12)	6.0	7.0

[a]Mean of (N) individual samples.

Table 9. Effect of Aroclor 1254 on the growth and survival of the midge *Tanytarsus dissimilis*

Mean measured concentration (µg/liter)	Test	Number of mature larval cases: Each test	Number of mature larval cases: Mean	Number of mature larval cases: Percentage of control	Number of pupal cases: Each test	Number of pupal cases: Mean	Number of pupal cases: Percentage of control
33	A	0			0		
	B	0	0	0	0	0	0
	C	0			0		
	D	0			0		
9.0	A	0			0		
	B	0	0.25	0.2	0	0	0
	C	0			0		
	D	1			0		
3.5	A	3			1		
	B	7	4.8	7.4	0	2	6.8
	C	14			5		
	D	–			–		
1.2	A	43			7		
	B	68	37	35	5	5.2	18
	C	4			2		
	D	35			7		
0.45	A	70			4		
	B	25	55	52	27	16	55
	C	82			16		
	D	48			16		
0.0	A	94			32		
	B	108	107	100	33	29	100
	C	119			22		
	D	–			–		

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MAY 28 1974

MONITORING FOR POLYCHLORINATED BIPHENYLS IN THE AQUATIC ENVIRONMENT

PROGRAMS UNDERWAY IN MICHIGAN WATERS

Report to: Lake Michigan Toxic Substances Committee
May, 1973

MICHIGAN WATER RESOURCES COMMISSION
BUREAU OF WATER MANAGEMENT
DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION BRANCH

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Programs Underway

1. State of Michigan

Michigan instituted a monitoring program for polychlorinated biphenyls (PCB's) early in 1971. The initial program consisted of a state-wide water sampling survey for determination of concentrations in inland waters and tributaries to the Great Lakes. Supplementary sampling has since been conducted on stream sediments, municipal raw water intakes, groundwater drinking supplies, sanitary landfill runoffs, municipal wastewater treatment plants, industrial discharges, and fish from both inland and Great Lakes waters. Sampling is being continued on a periodic basis for establishment of trends.

Quarterly water sampling in thirty Michigan tributaries showed that about 60 percent of the samples contained more than 0.01 ppb with one stream, the Saginaw River, having a high concentration of 2.9 ppb (Table 1). Fish from the Saginaw River had PCB concentrations as high as 165 ppm (Table 2). Five Michigan streams had mean concentrations in water samples over 0.10 ppb. These were all located in the populous southeastern lower peninsula which drains into lower Lake Huron, Lake St. Clair and Lake Erie. Of the Lake Michigan streams, the Grand and Kalamazoo rivers consistently showed the highest concentrations with means of 0.041 and 0.065 ppb, respectively.

A study of transport of PCB's to Lake Michigan on suspended solids was conducted during March-May, 1973, on the Grand, Kalamazoo and St. Joseph rivers. Sediment traps were suspended 1-2 meters off the bottom of the rivers and collected at varying time intervals in each river ranging from 3 times weekly to once a month. Concentrations of PCB's were notably higher in the settleable solids from the Kalamazoo River than from the Grand and St. Joseph rivers (Table 3). The over-all mean for all samples were 3.52, 0.99 and 0.97 ppm (oven-dry basis) for the Kalamzoo, Grand and St. Joseph rivers, respectively. This data substantiates earlier results indicating elevated levels of PCB's in the Kalamazoo River watershed. Extensive sampling at upstream sections of the watershed has identified past and

present wastepaper recycling by paper industries located in the City of Kalamazoo as the major source of contamination to the river. Certain sediment deposits in impoundments on Portage Creek, a tributary to the Kalamazoo River at Kalamazoo, were found to contain PCB's at concentrations exceeding 350 ppm (dry weight basis). Leaching from these PCB enriched sediments appears to be significant. Fish collected immediately downstream from the City of Kalamazoo were found to contain residues of PCB's in their tissue as high as 110 ppm (Hesse and Willson, 1972).

PCB concentrations in drinking water supplies from 45 intakes on the Great Lakes and connecting waters and an additional 20 on inland lakes and streams have generally been less than 0.01 ppb (Tables 4 & 5). Limited sampling of groundwater drinking supplies in southern Michigan has indicated that groundwater has not been significantly contaminated with PCB's.

Analyses of surface water runoff from sanitary and industrial landfills in Michigan suggest that these are a minor source of environmental contamination. Five of the 9 samples collected had PCB concentrations ranging from 0.04 to 0.30 ppb while the others contained less than 0.01 ppb.

Sampling of municipal wastewater treatment plant (WWTP) effluents throughout Michigan in 1971 and 1972 indicated that many WWTP's represent major point sources of PCB loss to surface waters of the state (Table 6). The average PCB concentration of 60 effluents sampled was 2.55 ppb. While only seven of the WWTP effluents exceeded 1 ppb, the Bay City WWTP located on the Saginaw River had an average effluent concentration of 120 ppb (high of 340 ppb), skewing the over-all average for all plants sharply upward. The average concentration excluding the Bay City WWTP was 0.56 ppb. Those WWTP's with PCB concentrations in effluents exceeding 1 ppb were, with one exception, located on rivers already identified as having high levels of PCB contamination. Sampling of 58 WWTP effluents in 1973 continues to show high PCB levels with an average concentration of 0.52 ppb (Table 7), including the Bay City plant. The PCB discharge from the

Bay City WWTP has been greatly reduced as a result of control measures in industries served by the WWTP.

Sampling of sewage sludge from 57 of the 58 WWTP's tested in 1973 showed Bay City to have the highest concentration of PCB's in the sludge being removed by the treatment process. The PCB concentration in the sludge from the Bay City plant was 352 ppm (dry weight basis) compared to a state-wide average of 15.6 ppm (Table 8).

In an attempt to identify major contributors of PCB's within municipal WWTP systems, sampling at key points in the interceptor systems has been conducted within the municipalities of Bay City, Mt. Clemens, Saginaw, Adrian, Detroit and Kalamazoo. This program has been very successful. The City of Detroit has, in fact, established an on-going sampling program within their interceptor system with analytical assistance from the State. They are applying a new City of Detroit sewer ordinance which limits discharges within the wastewater system to a maximum of 0.1 ppb.

A broad scale sampling of industrial discharges throughout Michigan has shown results indicative of the widespread usage of PCB's. Nearly half of the industrial discharges sampled have contained more than 0.1 ppb with many in excess of 1 ppb. The highest concentration detected in an industrial discharge in Michigan has been 7,200 ppb. Automotive plants, chemical companies, and paper product manufacturers are among the types of industries with highest concentrations. Also industries and building complexes; including some schools and hospitals; with heat transfer systems appear to be another major source. Industries identified as sources of PCB pollution have been encouraged to changeover to replacement compounds or to clean up their operation so that discharges of PCB's do not exceed the present Michigan guideline of 0.1 parts per billion.

Michigan is currently trying to get a handle on losses from electrical transformers in leakage, servicing, and replacement within plants. It appears that many of the small transformer maintenance companies are still dumping PCB's down the drain rather than returning them for incineration.

An example of one location in Michigan where monitoring and subsequent control measures have resulted in a marked reduction in PCB contamination is the Saginaw River basin. Even though it is not within the Lake Michigan watershed, the Saginaw River PCB situation is worthy of review. Monitoring of major Great Lakes tributaries during 1971-1972 identified the Saginaw River as having the highest concentrations of PCB's of any tributary within Michigan boundaries. Intensive sampling throughout the river basin in search of point sources successfully isolated ten major points of PCB discharge to the river system. Each of the industrial sources were asked to identify the cause of their losses and to take corrective action. Control measures, in most cases, conversion to non-PCB containing products, have proved very effective toward lowering the PCB concentrations in the Saginaw River. A sharp PCB decline at a monitoring site near the river mouth was observed (Table 9) in October, 1972, and concentrations have remained low since that date. It is hoped that a corresponding decline in PCB concentrations in fish from the river and Saginaw Bay will soon be observed.

In 1972 Michigan developed a cooperative State-Federal study of contaminant levels in Great Lakes fish species including lake trout, salmon, whitefish, chubs, menominee, yellow perch, alewife, carp, and suckers. Fish from Lakes Michigan, Huron, Erie, and Superior are systematically being sampled on an annual basis to obtain information on areas where contaminants approach or exceed FDA guidelines for consumer protection. The project, developed by the State agencies in cooperation with the U. S. Food and Drug Administration and the Bureau of Sport Fisheries and Wildlife Great Lake Laboratory, will establish patterns of residues of mercury, PCB's, DDT and dieldrin in Great Lakes fish. Table 10 shows the concentrations of PCB's detected in fish from Lake Michigan during the first year of this study. PCB's in Salmonids (lake trout, steelhead, coho salmon, and chinook salmon) and chubs were shown to exceed the FDA guideline of 5.0 ppm while concentrations in other species did not exceed this guideline.

Table 1. Mean PCB Concentrations in Michigan Tributaries to the Great Lakes in 1971-72.

Lake Basin	River	PCB's (ppb as 1254)	Range (ppb as 1254)
Michigan	St. Joseph	0.013	<0.010-0.039
	Kalamazoo	0.065	0.019-0.097
	Grand	0.041	0.011-0.080
	Muskegon	0.010	<0.010-0.037
	Manistee	0.014	<0.010-0.039
	Boardman	0.017	<0.010-0.044
	Elk	0.012	<0.010-0.039
Huron	Saginaw	1.100	0.450-2.900
	Cass[1]	0.014	<0.010-0.048
	Flint[1]	0.078	0.010-0.150
	Shiawassee[1]	0.029	<0.010-0.073
	Tittabawassee[1]	0.140	<0.022-0.230
	Au Sable	<0.010	<0.010-0.010
	Thunder Bay	0.023	<0.010-0.037
	Cheboygan	0.032	<0.010-0.053
St. Clair	Clinton	0.150	<0.039-0.430
	Black	0.043	<0.010-0.110
	St. Clair	0.010	<0.010-0.029
Erie	Raisin	0.210	<0.068-0.500
	Huron	0.012	<0.010-0.039
	Rouge[2]	0.470	0.058-1.600
	Detroit	0.020	<0.010-0.053

[1]Tributary to Saginaw River
[2]Tributary to Detroit River downstream from Detroit River sampling station

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... poly-chlorinated biphenyls (PCB's) in fish from Saginaw River, December 7, 1971. (ppm; wet weight).

Species	Location	Length	Percent fat	PCB's based upon 1242 standard
Perch	Karn-Weadock Discharge Channel	9.0	1.3	16.3
Carp	" " " "	21.0	0.9	8.8
Catfish	" " " "	8.0	7.0	37.1
Catfish	" " " "	7.5	4.9	47.9
Carp	U.S. Coast Guard Station	23.0	---	48.0
Carp	" " " "	24.0	10.5	20.4
Carp	" " " "	20.0	6.5	15.5
Carp	" " " "	24.0	5.9	45.8
Carp	" " " "	21.0	4.6	30.2
Pike	" " " "	27.0	1.6	16.6
Pike	" " " "	23.0	1.1	6.9
Gizzard Shad	" " " "	14.0	17.5	165.3
Gizzard Shad*	" " " "	6.0	15.3	32.5
Gizzard Shad*	" " " "	4.5	15.0	161.9
Gizzard Shad*	" " " "	5.0	17.0	77.0
Gizzard Shad*	Zilwaukee Bridge	4.5	15.7	24.1
Gizzard Shad*	" "	5.0	9.6	52.0
Gizzard Shad*	" "	5.0	8.7	10.4

* Concentration based upon analysis of whole fish. All others based upon edible portion only.

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Table 3. Concentrations of PCB's (polychlorinated biphenyls) in the settleable solids collected from the mouths of the Grand, Kalamazoo, and St. Joseph Rivers; Spring 1973, for comparison of variable sampling periods. Concentrations in ppm on an oven-dry basis.

River	Sample Type [a]	Sample Dates 3/21	3/23	3/30	4/2	4/4	4/6	4/9	4/11	4/13	4/20	4/27	4/30	5/2	5/4	5/1
Grand	3X	3.24			1.6*	0.95	1.0	<0.1	0.93	1.58			0.83	3.5	0.53	
	Weekly		1.25	0.94			1.1			1.00	0.55	0.74			0.80	0.7
	Biweekly			0.85						0.73		0.50				0.6
	Monthly									1.41						0.5
															Mean	*
Kalamazoo	3X	6.7	27.5		2.08	<0.1	2.62	1.33	3.20	<0.1			3.11	3.50	3.75	
	Weekly		6.83	3.0			3.54			3.77	3.09	2.98			2.88	4.8
	Biweekly			3.77						2.54		2.64				2.5
	Monthly									2.11						3.14
															Mean	=
St. Joseph	3X								2.13	0.68		0.95	0.63	0.82		
	Weekly									0.85		0.75		0.83	1.21	
	Biweekly											0.67			0.95	
	Monthly														0.83	
															Mean	*

[a] 3X = Sample collected Mon, Wed. and Friday

* Concentration based upon a 1:1 ratio of Aroclor 1242 and 1254. All other concentrations calculated as Aroclor 1242.

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Table 4. PCB concentrations in interstate water intake samples, Spring 1971.

Location	Collection Date	PCB's as Aroclor 1254 (ppb)
St. Clair River		
Port Huron	3-11-71	< 0.010
Marysville	3-11-71	< 0.010
St. Clair	3-11-71	< 0.010
E. China Twp.	5-17-71	< 0.010
Marine City	3-11-71	< 0.010
Algonac	4-21-71	0.028
Lake St. Clair		
Fairhaven	5-17-71	< 0.010
New Baltimore	4-21-71	< 0.010
Mt. Clemens	4-21-71	< 0.010
Grosse Pte. Farms	4-21-71	< 0.010
Detroit River		
Detroit-E. Jefferson Ave.	4-21-71	< 0.010
Wyandotte	2-9-71	< 0.010
Detroit-Allen Park	2-9-71	< 0.010
Lake Erie		
Monroe	2-9-71	< 0.010
Lake Superior		
White Pine Mine	4-28-71	< 0.010
Eagle Harbor	5-26-71	< 0.010
Copper Harbor	5-26-71	< 0.010
Gay	5-26-71	< 0.010
Baraga	4-28-71	< 0.010
L'Anse	4-28-71	< 0.010
Marquette	4-28-71	< 0.010
Munising	4-28-71	< 0.010
Sault Ste. Marie	5-27-71	< 0.010
Lake Huron		
St. Ignace	2-25-71	< 0.010
Alpena	4-8-71	< 0.010
East Tawas	3-3-71	< 0.010
Saginaw-Midland	3-3-71	0.011
Pinconning	3-3-71	< 0.010
Bay City	4-8-71	< 0.010
Lake Michigan		
South Haven	3-9-71	< 0.010
Holland	4-14-71	< 0.010
Grand Rapids	4-14-71	< 0.010
Muskegon	3-9-71	< 0.010

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Table 4. Continued.

Location	Collection Date	PCB's as Aroclor 1254 (ppb)
Ludington	3-9-71	<0.010
Traverse City	3-2-71	<0.010
Escanaba	2-25-71	0.177
Gladstone	2-25-71	<0.010
Menominee	3-23-71	<0.010
Bridgeman	4-14-71	<0.010

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Table 5. Continued.

Location	Collection Date	PCB's as Aroclor 1254 (ppb)
Saginaw-Midland	6-20-72	<0.010
Pinconning	6-20-72	<0.010
Bay City	6-20-72	0.046*
Port Hope	6-20-72	<0.010
Harbor Beach	6-20-72	<0.010
Chippewa River		
Mt. Pleasant	6-21-72	<0.010
Pine River		
Alma	5-19-72	0.027

*PCB's as Aroclor 1242

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Table 5. PCB concentrations in Michigan water intake samples, 1972.

Location	Collection Date	PCB's as Aroclor 1254 (ppb)
St. Clair River		
Port Huron	5-16-72	<0.010
Marysville	5-16-72	<0.010
St. Clair	5-16-72	<0.010
E. China Twp.	5-22-72	0.032
Marine City	5-16-72	<0.010
Algonac	5-16-72	0.019
Lake St. Clair		
Fairhaven	5-16-72	<0.010
New Baltimore	5-16-72	<0.010
Mt. Clemens	5-16-72	<0.010
Grosse Pte Farms	5-16-72	<0.010
Detroit River		
Detroit-E. Jefferson Ave.	5-16-72	<0.010
Wyandotte	5-15-72	<0.010
Detroit-Allen Park	5-16-72	<0.010
Lake Erie		
Monroe	5-15-72	<0.010
Huron River		
Ann Arbor	5-15-72	<0.010
Flat Rock	5-15-72	<0.010
Ypsilanti	5-15-72	<0.010
River Raisin		
Adrian	5-15-72	<0.010
Blissfield	5-15-72	<0.010
Deerfield	5-15-72	<0.010
Dundee	5-15-72	0.013
Lake Michigan		
Bridgeman	5-23-72	<0.010
St. Joseph	5-18-72	<0.010
Benton Harbor	5-18-72	<0.010
South Haven	5-18-72	<0.010
Holland	5-18-72	<0.010
Grand Rapids	5-18-72	<0.010
Muskegon	5-18-72	<0.010
Ludington	5-19-72	<0.010
Northport Point	6-21-72	<0.010
Traverse City	6-21-72	<0.010
Escanaba	8-28-72	<0.010
Gladstone	8-28-72	<0.010
Menominee	8-28-72	<0.010

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Table 5, Continued

Location	Collection Date	PCB's as Aroclor 1254 (ppb)
Lake Michigan (Cont.)		
Grand Rapids	5-18-72	<0.010
Rogue River		
Rockford	5-18-72	<0.010
Muskegon River		
Big Rapids	5-19-72	<0.010
Elk Lake		
Elk Rapids	6-21-72	<0.010
Indian River		
Manistique	8-28-72	<0.010
Lake Antione		
Iron Mountain	8-29-72	<0.010
Lake Fumee		
Norway	8-29-72	<0.010
Lake Superior		
White Pine Mine	8-29-72	<0.010
Eagle Harbor	8-30-72	<0.010
Copper Harbor	8-30-72	<0.010
Gay	8-30-72	<0.010
Baraga	8-30-72	<0.010
L'Anse	8-30-72	<0.010
Marquette	11-24-72	<0.010
Munising	8-31-72	<0.010
Sault Ste. Marie	8-31-72	<0.010
Black River		
Ramsey	8-29-72	<0.010
Lake Sally		
Ishpeming	8-30-72	<0.010
Teal Lake		
Negaunee	8-30-72	<0.010
Lake Huron		
Mackinaw Island	8-31-72	<0.010
St. Ignace	9-7-72	<0.010
St. Ignace	12-14-72	<0.010
Alpena	6-21-72	<0.010
East Tawas	6-20-72	<0.010

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Table 6

Polychlorinated Biphenyls (PCB's) in Effluents of Municipal Wastewater Treatment Plants throughout Michigan 1971-1972. Unless specified, all samples are 8 hr. composites.

CITY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
Adrian	3-30-72	1.80	4.60
	6-13-72	14.00	
	6-14-72	6.90	
	9-6-72	0.41	
Albion	3-28-72	0.44	0.44
Ann Arbor	10-14-71	0.14	0.12
	3-30-72	<0.10	
Battle Creek	10-5-71	0.39	0.39
	3-28-72	0.16	
	2-21-72	0.92	
	6-6-72	0.28	
	6-7-72	0.21	
Bay City	11-4-71	340.00	120.00
	11-22-71	210.00	
	11-23-71	60.00	
	3-2-72[a]	290.00	
	4-4-72	19.00	
	6-13-72	11.00	
	6-14-72	25.00	
	9-14-72	5.70*	
Benton Harbor - St. Joseph	10-28-71	0.99	0.65
	4-4-72	0.31	
Brighton	10-5-71	0.38	0.38
Charlotte	7-20-72	0.61	0.61
Constantine	4-4-71	0.85	0.85
Detroit	10-14-71	2.20	1.95
	12-20-72[c]	3.00	
	1-20-72	0.92	
	3-9-72	2.40	
	4-17-72[b]	1.80	
	6-1-72	0.88	
	10-19-72	2.50**	
Dexter	10-14-71	<0.10	0.10

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Table 6
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CITY	DATE	PCB's Aroclor 1254 (ppb)	Mean Conc. (ppb)
E. Lansing	11-15-71	0.69	0.51
	4-3-71	0.35	
Escanaba	12-16-71	0.29	0.29
Essexville	11-4-71	0.21	0.24
	3-31-72	0.28	
Flint	10-5-71	1.30	0.68
	3-31-72	0.92	
	6-7-72	0.47	
	6-8-72	0.30	
	10-5-72	< 0.10	
Flushing	10-5-72	0.52	0.52
Gladstone	7-21-72	0.19	0.19
Grand Haven	4-4-72	< 0.50	< 0.50
Grand Rapids	11-15-71	0.37	0.52
	3-30-72	0.68	
Holland	10-20-71	0.79	0.60
	3-29-72	0.42	
Houghton-Hancock	3-21-72	<.0.10	0.10
Iron Mountain-Kingsford	3-21-72	0.55	0.87
	4-4-72	1.20	
Ironwood	3-20-72	0.16	0.16
Jackson	11-16-71	<0.10	<0.10
	2-21-72	<0.10	
	3-28-72	<0.10	
Kalamazoo	10-5-71	1.30	0.66
	3-28-72	0.83	
	6-6-72	0.48	
	6-7-72	0.53	
	12-6-72	0.19e	
L'Anse	4-21-72	<0.10	<0.10
Lansing	10-7-71	0.23	0.18
	4-4-72	0.13	

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CITY	DATE	PCB/s Aroclor 1254 (ppb)	Mean Conc. (ppb)
Manistique	12-15-72	<0.20	<0.20
Marquette	12-14-71	0.35	0.35
Marshall	3-28-72	<0.10	<0.10
Menominee	12-15-71	0.35	0.35
Midland	2-2-72	0.29	0.23
	3-31-72	0.40	
	4-14-72	0.13	
	[d]10-2-72	0.13	
Milford	10-14-71	<0.10	<0.10
Monroe	11-15-71	0.60	0.46
	3-30-72	0.33	
Mt. Clemens	11-15-71	1.40	5.21
	3-30-72	2.90	
	6-7-72[c]	4.50	
	6-8-72[c]	3.10	
	7-26-72	9.40	
	8-2-72	10.00	
Mt. Pleasant	3-31-72	<0.10	<0.10
Muskegon	11-15-71[c]	0.28	0.28
Muskegon Heights	11-15-71[c]	0.37	0.37
Niles	4-4-72	0.68	0.68
Norway	4-5-72	0.40	0.40
Ontonagon	4-21-72	<0.10	<0.10
Owosso	9-14-72	<0.10	<0.10
Parchment	4-20-72	<0.10	<0.10
Pontiac (Auburn Rd.)	11-17-71	<0.10	0.35
	3-30-72	0.61	
Pontiac (E. Blvd.)	11-17-71	0.20	0.45
	3-30-72	1.30	
	6-6-72	0.15	
	6-7-72	0.16	
Portage	11-15-71[d]	1.90	1.90

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CITY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
Port Huron	11-15-71	0.28	0.40
	3-30-72	0.52	
Saginaw	10-6-71	1.10	1.80
	3-31-72	3.80	
	6-7-72	2.00	
	6-8-72	1.50	
	10-4-72[d]	0.74	
St. Ignace	12-15-72	<0.20	<0.20
South Haven	4-4-72	<0.10	<0.10
Swartz Creek	10-5-72	<0.10	<0.10
Three Rivers	4-4-72	<0.30	<0.30
Trenton	11-16-71	0.14	0.53
	3-30-72	1.10	
	6-6-72	0.47	
	6-7-72	0.91[e]	
Warren	11-15-71	0.16	0.13
	3-30-72	0.10	
Wayne County (Wyandotte)	11-16-71	0.64	0.40
	3-30-72	0.17	
White Pine	4-21-72	0.2	0.20
Wyoming	11-30-72[c]	0.44	0.49
	3-30-72	0.55	
Ypsilanti	11-16-71	0.22	0.21
	4-2-72	0.21	
Ypsilanti Twp #1	11-16-71	0.12	0.11
	4-2-72	<0.10	
Ypsilanti Twp #2	11-16-71	0.19	0.17
	4-2-72	0.16	

*Aroclor 1242 Standard
**Aroclor 1242 and 1254 in 1:1 ratio

[a]6 hr [b]10 hr [c]24 hr [d]Grab [e]hexane lost GRAND MEAN 2.55

Table 7. Concentrations of PCB's in the Final Effluent from Wastewater Treatment Plants throughout Michigan, Spring, 1973. Concentrations in parts per billion dry weight.

CITY	DATE	PCB's		
		1242	1254	1242+1254
Adrian	3/7			0.26
Albion	2/22		0.34	
Ann Arbor	3/1		0.25	
Bay City	3/1	3.20		
Battle Creek	2/28		<0.10	
Benton Harbor-St. Joseph	2/28		0.20	
Brighton	3/1			0.33
Cadillac	3/28		0.53	
Charlotte	5/1		0.34	
Constantine	2/28		0.46	
Detroit	2/28	2.15		
Dexter	3/1		0.23	
East Lansing	5/2		0.18	
Escanaba	3/28			0.28
Essexville	3/1		0.10	
Flint	2/22		<0.10	
Gladstone	3/28		0.44	
Grand Haven	2/21		<0.10	
Grand Rapids	2/21		1.05	
Holland	2/21		<0.10	
Houghton-Hancock	3/27		0.18	
Iron Mountain-Kingsford	3/28		0.69	
Ironwood	3/27			0.29
Jackson	2/22		<0.1	
Kalamazoo	2/29			1.12
L'Anse	3/27			0.31
Lansing	4/18		0.22	
Manistique	3/28		0.63	
Marquette	3/27		0.29	
Marshall	2/22		0.15	
Menominee	2/28		0.57	
Midland	3/1		<0.10	
Milford	3/8			2.20
Monroe	5/4		<0.10	
Mt. Clemens	3/8			2.90
Mt. Pleasant	3/28		0.29	
Muskegon	2/28		0.88	
Muskegon Heights	2/28		0.18	
Niles	2/20		0.48	
Norway	3/28		<0.10	
Owosso	2/21		0.12	
Pontiac (Auburn)	3/12			0.60
Pontiac (E. Blvd.)	3/12			0.54
Port Huron	3/8			1.80
Saginaw	3/1			0.77
Sault Ste. Marie	3/28		0.73	

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CITY	DATE	PCB's 1242	1254	1242:1254
St. Ignace	3/28		0.31	
Three Rivers	2/21		<0.10	
Traverse City	3/7		<0.10	
Trenton	2/28		<0.10	
Warren	2/27		<0.10	
Wayne County	2/28		0.40	
Wyoming	2/21		0.22	
Ypsilanti	2/28			0.31
Ypsilanti Twp #1	3/1		<0.10	
Ypsilanti Twp #2	3/1		<0.10	

*Concentrations based on best fit of 3 standards: Aroclor 1242, Aroclor 1254, or a mixture of Aroclor 1242 and 1254 in a 1:1 ratio.

Table 8. Concentrations of PCB's in the sludge from fifty-seven municipal wastewater treatment plants in Michigan, Spring 1973. Concentrations in parts per million, dry weight.

City	Date	PCB's* 1242	1254	1242:1254
Adrian	3/ 7			24.0
Albion	2/22		1.5	
Ann Arbor	3/1		1.1	
Bay City	3/1	352.0		
Battle Creek	2/28		2.8	
Benton Harbor-St. Joseph	2/28		13.8	
Brighton	3/1		<0.1	
Cadillac	3/28		<0.1	
Charlotte	5/1		6.8	
Constantine	2/28		2.1	
Detroit	2/28	32.1		
Dexter	3/1		3.2	
E. Lansing	5/2		4.6	
Escanaba	3/28		5.9	
Essexville	3/1		3.9	
Flint	2/22		6.3	
Gladstone	3/28		4.1	
Grand Haven	2/21		4.1	
Grand Rapids	2/21		11.8	
Holland	2/21		0.8	
Howell	4/26		15.0	
Houghton-Hancock	3/27		5.5	

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Table 8. Continued.

City	Date	PCB's 1242	1254	1242:1254
Iron Mountain - Kingsford	3/28		9.5	
Ironwood	3/27		5.2	
Jackson	2/22		3.0	
Kalamazoo	2/29	23.3		
L'Anse	3/27		4.4	
Lansing	4/18		5.3	
Manistique	3/28		1.5	
Marquette	3/27		2.8	
Marshall	2/22		3.9	
Menominee	2/28		4.2	
Midland	3/1		2.9	
Milford	3/8			50.5
Monroe	5/4		3.3	
Mt. Clemens	3/8	175.0		
Mt. Pleasant	3/28		6.5	
Muskegon	2/28		12.7	
Muskegon Heights	2/28		11.0	
Niles	2/20		7.8	
Norway	3/28		<0.1	
Owosso	2/21		2.0	
Pontiac (Auburn)	3/12			12.1
Pontiac (E. Blvd.)	3/12			9.2
Port Huron	3/8			9.2

Table 8. Continued.

City	Date	PCB's 1242	PCB's 1254	1242:1254
Saginaw	3/1		5.0	
Sault Ste. Marie	3/28		2.4	
St. Ignace	3/28		1.5	
Three Rivers	2/21		4.1	
Traverse City	3/7		1.8	
Trenton	3/28		<0.1	
Warren	2/27		<0.1	
Wayne County	2/28	2.0		
Wyoming	2/21		0.58	
Ypsilanti	2/28		2.0	
Ypsilanti Twp. #1	3/1		<0.1	
Ypsilanti Twp #2	3/1		<0.1	

* Concentration based on best fit of 3 standards: Aroclor 1242, Aroclor 1254, or a mixture of Aroclor 1242 and 1254 in a 1:1 ratio.

Table 9. Polychlorinated biphenyls (PCB's) in composite water samples from the Saginaw River at Bay Harbor Marina, March 1971 - May 1973.

Collection Date	Concentration in parts per billion
3-9-71	0.450
6-10-71	0.560
8-27-71	2.900
10-26-71	1.100
6-8-72	0.640
10-13-72	0.360
10-29-72	<0.020
10-30-72	<0.020
11-1-72	0.091
11-2-72	0.031
11-4-72	<0.020
11-6-72	0.022
1-26-73	<0.100
5-24-73	0.210

Table 10. Concentrations of polychlorinated biphenyls (PCB's) found in fish species taken from Michigan waters of Lake Michigan during 1972*.

Species	PCB's by District**in ppm (sample size in parenthesis) MM3	MM4	MM5	MM6	MM7	MM8	Total # Fish Sampled	Mean Concentration
Lewife	1.7 (3)			2.3 (1)	2.7 (6)	2.7 (6)	16	2.4 ± 0.6
Carp					3.9 (6)		6	3.9 ± 2.0
Chub				3.2 (2)	8.5 (8)	6.5 (9)	19	7.0 ± 4.2
Menominee				0.8 (1)	1.2 (2)		3	1.1
Perch				0.5 (1)	0.4 (5)	0.5 (11)	17	0.4 ± 0.4
Coho Salmon			11.2 (3)				3	11.2
Chinook Salmon				12.4 (10)			10	12.4 ± 5.0
Suckers	0.8 (6)			0.7 (2)	1.5 (3)	1.1 (6)	17	1.0 ± 0.7
Steelhead			6.0 (2)				2	6.0
Lake Trout	11.1 (3)	6.4 (3)		3.2 (2)	5.7 (6)	9.2 (6)	20	7.4 ± 4.0
Whitefish		0.6 (3)		0.8 (2)	1.1 (1)		6	0.7 ± 0.3

Data from Michigan's Great Lakes Environmental Contaminant Survey, 1972.
Zones of Lake Michigan within Michigan Boundaries
MM3 - Northern Basin
MM4 - Grand Traverse Bay
MM5 & MM6 - Central Basin
MM7 & MM8 - Southern Basin

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References Cited

Hesse, J. L and Ronald Willson, 1972. Evaluation of the Aquatic Environment of the Kalamazoo River Watershed, Part A: Biological Survey, June-August, 1971. Michigan Water Resources Commission Report.

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It has been established that Lake Michigan is unique in that it contains much higher concentrations of agricultural pesticides than the other Great Lakes due, in part, to the large useage in the watershed in comparison to the flushing period for the lake and to the relatively low biomass density. Previous studies have shown that the fish from Lake Michigan approached the FDA action levels for dieldrin in 1969 and that a major fraction exceeded the action levels for DDT (Reinert, 1970). More recent data (Reinert, 1972) from carefully designed monitoring (Reinert, 1971) indicates that the average DDT concentration in Lake Michigan fish remained essentially the same between 1967 to 1970 and suggested that the levels have begun to decrease.

Although not realized in the early analyses by Reinert, other work (Veith, 1970) has shown that the concentration of PCB's (similar to Aroclor 1254) were greater than 15 ug/gm in large fish collected from Lake Michigan in 1969. Thus, it is apparently in Lake Michigan rather than the other Great Lakes that the potentially hazardous and persistent chemicals from our industrialized technology are most concentrated. It follows, then, that consideration must be given to the effect these chemicals have on the biological communities sustained by Lake Michigan and the possibility of stemming or even reversing the trend of increasing levels of organochlorine compounds in the Lake Michigan system.

Despite the comparatively high levels of DDT, dieldrin and PCB's in Lake Michigan, there is no direct evidence that the chemicals are endangering the aquatic life in the lake. The concentration of each of the chemicals appears to be below 10 ng/l in the pelagic waters and less than 100 ng/l in the nearshore waters, all of which are below the "no effect" level for the respective chemicals for most aquatic organisms. However, the lack of direct evidence of damage may simply reflect the difficulty in adequately measuring such effects in this environment.

There is considerable indirect evidence which suggests that the buildup of organochlorine compounds may be a threat to the future of the biological resources of the lake. It is beyond the scope of this introduction to review the literature concerning the pesticides and PCB's, and the reader is referred to existing comprehensive reviews (Zitko and Choi, 1971; NIH, 1972; Quinby, 1972; Task Force, 1972).

In laboratory experiments crustacea exposed to varying levels of Aroclor(R) 1254 in the water concentrate the PCB within their bodies more than 20,000 times. The tissue residues may sometimes reach an equilibrium and in Gammarus fasciatus PCB did not concentrate beyond 27,000 times despite an additional 3-week exposure to 1.6 ug/l Aroclor(R) (Saunders, 1971). In contrast, PCB residues in crayfish did not reach equilibrium after a 23 day exposure. PCB concentration factors by two estuarine fishes, Lagondon rhomboides and Leiostomus xanthurus, was similar to that described above for crustaceans -- about 10,000 to 50,000 times the exposure levels in water (Hansen, et al., 1971).

It is important to note that these accumulations occurred at water concentrations of PCB that killed the fish in 15 to 45 days.

Also similar were the accumulation ratios of 26,000 to 56,000 for bluegills (Lepomis macrochirus) chronically exposed to 2-15 ug/l of Aroclor(R) 1248, and 1254. Fathead minnows (Pimephales promelas) chronically exposed to Aroclor(R) 1242 and 1254 for 8 months concentrated PCB's 100,000 and 200,000 times the exposure levels, respectively. Residues of 50 ug/l (whole body) resulted from exposure for 8 months to 0.3 ug/l Aroclor(R) 1254. These experiments with bluegills also indicated that the maximum levels of PCB were generally related to the concentration of PCB in the water (50,000 - 200,000 times higher) to which they were exposed (Stalling and Huckins, unpublished data, 1971).

Effects on Reproduction

PCB residues in salmon eggs are apparently related to mortality of eggs. In preliminary investigations in Sweden, Jensen, Johansson, and Olsson (1970) reported that when residues in groups of eggs ranged from 0.4 to 1.9 ug/l on a whole weight basis (7.7 to 34 ug/g on a fat basis), related mortalities ranged from 16 percent up to 100 percent.

As indicated in Table I, Aroclor 1248 was the most toxic of the eight aroclors tested to Daphnia magna in static tests, with a 3-week LC50 of 25 ug/liter. Aroclor 1254 was most toxic under continuous-flow conditions with a 3-week LC50 of 1.3 ug/liter. The Aroclors were more toxic under continuous-flow than static conditions, with 16 percent impairment of reproduction caused by 1.0 ug/liter Aroclor 1248.

The calculated 96-hour LC50 values for newly-hatched fathead minnows were 7.7 ug/l for Aroclor 1254 and 15 ug/l for 1242. Three-month-old fatheads had a 96-hour LC50 of ca. 300 ug/l for 1242. Reproduction occurred at and below 1.8 ug/l 1254 and at and below 5.4 ug/l 1242. Polychlorinated biphenyls were acutely toxic but exhibited much greater chronic toxicity at very low levels, due to their cumulative nature. Newly hatched young were the most sensitive life stage. Young fathead growth was also affected above 2.2 ug/l 1248 and none survived above 5.1 ug/l after 30 days. Young flagfish, Jordanella floridae, did not survive above 5.1 ug/l 1248 and did not grow well above 2.2 ug/l.

The ninety-six hour LC50 values for Aroclor 1242 and 1248 with Gammarus pseudolimnaeus were 73 and 29 ug/liter. Survival after 30 days was 53 percent at 8.7 ug/l 1242 and 52 percent at 5.1 ug/l 1248. Good reproduction and survival of young occurred at 2.8 ug/l 1242 and 2.2 ug/l 1248.

Abundant adult emergence of the midge Tanytarsus dissimilis did not occur above 5 ug/l 1248 or 3.5 ug/l 1254. The calculated 3-week LC 50 (50 percent reduction based on control as 100 percent) for Aroclor 1254 was 0.65 ug/l for larvae and .45 ug/l for pupae.

Application factors of 0.10 for 1242 and 0.15 for 1248 were calculated for the PCB's and Gammarus. Application factors of 0.2 for 1254 and 0.16 for 1242 were calculated for fathead minnows using newly hatched fish to obtain the 96-hour LC50.

The second generation fry from adults previously exposed to the PCB mixtures were exposed to the respective mixtures for 30 days after hatching. Preliminary data analyses indicated that 3 ug/l of Aroclor(R) 1248 caused no mortality but a 20 percent reduction in the weight of the fry. Similarly, Aroclor(R) 1260 caused no mortality when the fry were exposed to 2.1 ug/l; however, the weight of the fry was reduced by 33 percent.

The residue data from the trout exposed for 27 weeks indicate that approximately 0.55 ug/l of Aroclor(R) 1254 will result in 5 ug/gm of the PCB mixture in the fish (whole fish basis). The concentration in the fillet of fish exposed to 0.84 ug/l Aroclor(R) 1254 was 1 ug/gm. The lipid content of the fillet portion of the trout was less than two percent.

Dietery exposure to PCB seems to be less of a direct hazard to fish than exposure in water. Coho salmon (Oncorphynchus kisutch) fed Aroclor(R) 1254 in varying amounts up to 14,500 ug/kg body weight per day accumulated whole body residues which were only 0.9 to 0.5 of the level in the food after 240 days of dietary exposure. Growth rates were not affected. However, all fish exposed to the highest treatment died after 240 days exposure; and thyroid activity was stimulated in all except the group treated at the lowest concentration (Mehrle and Grant, unpublished data, 1971).

The massive trout and salmon stocking program in Lake Michigan has produced an unparalleled sport fishery and provides a valuable protein source for human food as well as animal feeds. Essential to the establishment and maintenance of this fishery is the successful reproduction of the adult fish. However, Reinert (1970) has previously pointed out that DDT and dieldrin levels in eggs are similar to those which inhibited reproduction in the studies of Burdick et al. (1964) and Macek (1968). In addition, Jensen et al. (1970) have shown that 15 ug/gm of PCB's (lipid basis) in salmon eggs produced 50 percent mortaility and complete mortality can be expected when the eggs contain 25 ug/gm PCB's (lipid basis). All of these data concerning the effects of organochlorine compounds on reproduction were obtained individually, and little is known of possible combined effects when the tissue contains mixtures of the toxicants.

Even though the continued stocking of fish may maintain a food resource in spite of possible adverse effects of the residues on reproduction in Lake Michigan fish, many fish contain body burdens which make the fish unfit as a food resource for humans. The U.S. Food and Drug Administration has established a tolerance level of 5 ug/gm, 5 ug/gm and 0.3 ug/gm for DDT, PCB's and dieldrin, respectively, in food to be sold for human consumption. Since the lake supports a sizeable commercial fishery in addition to the sport fishery, the presence of these chemicals below the "no effect" level in water may still endanger these industries due to the large partition

coefficient for lipid/water systems. Indeed, numerous catches of commercial fish being shipped to markets have been seized, and tons of large salmon have been withdrawn from state give-away programs in Michigan because the DDT and PCB residues exceeded the 5 ug/gm concentration.

Concern has also arisen with respect to the impact the organochlorine compounds in the Lake Michigan biota (principally fish) is having on other animals which use this food supply. Most notably is the effect of Lake Michigan fish on mink reproduction in the North Central states. Before DDT and dieldrin levels in these fish were well documented, Hartsough (1965) indicated that Lake Michigan fish were suspected as the factor leading to poor mink reproduction. Aulerich et al. (1970) clearly demonstrated the fish had been the cause of the reproductive failure. Aulerich and Rinber (1970) found that DDT and DDD did not have significant adverse effects on mink. Furthermore, dieldrin was lethal at 2.5 ug/gm in the food for extended periods but did not appear to effect reproduction at twice this level during the gestation period. Aulerich et al. (1971) concluded that coho salmon per se did not cause reproduction problems but that the disorder is associated with other species of fish and "appears to be dependent upon the species of fish and its environment." Finally, after the earlier reports that PCB's were present in Lake Michigan fish, Ringer et al. (1972) demonstrated that 10 ug/gm of Aroclor 1254 in coho salmon produced 71 percent mortality in mink and that a mixture of 10 ug/gm PCB's and 0.5 ug/gm dieldrin in coho feed produced 100 percent mortality. No kits were born alive when the diet contained 5 ug/gm or greater Aroclor 1254 alone. This evidence clearly indicates that the biological resources of Lake Michigan may seriously endanger other species even though the levels of toxicants are not sufficiently great to produce a dramatic effect within the aquatic communities.

Equally important is the coincidence of high levels of chlorinated hydrocarbon in herring gull and other bird populations with reproductive failures and subsequent population decline. Ratcliffe (1970) and Anderson (1970) have clearly shown that major changes in eggshell thickness have occurred since 1945 and that the phenomenon may be a major factor in the decline, if not extinction, of many species of birds. In general, egg shell thinning of 10 to 15 percent (relative to pre-1940 eggs) may produce an effect in the population, 15 to 20 percent is associated with readily observable egg breakage, and 50 percent thinning has been associated with virtually total reproductive failure (Risebrough et al., 1970: Keith et al., 1970).

Anderson (1970) found the Great Lakes Herring Gulls contained the highest chlorinated hydrocarbon levels in eggs ever reported for that species. He also found that the Lake Michigan gull, which declined dramatically in the early 1960's but recovered in the late 1960's, had egg shell thinning which varied from nine percent in 1953-1956 to 18 percent in 1965. However, since 1965, the degree of thinning

has decreased to eight percent in 1969. In comparison, gulls on Lake Huron and Lake Superior have exhibited thinning of seven and eight percent, respectively, and those from the east coast have remained essentially unchanged from earlier eggs.

Anderson (1970) also showed that double-crested cormorants from Wisconsin had 20 percent thinner eggs and produced eggs with the highest DDE concentrations of this species from interior North America. Golden eagles which primarily feed on mammals do not show as dramatic egg shell thinning as do the Bald Eagles which feed on fish. Despite the lack of detailed data in the literature, it is not unreasonable to suggest that the disappearance of Bald Eagles from the shores of Lake Michigan may also be linked by correlation to the chlorinated hydrocarbons in the food resources of the lake.

The Lake Michigan system is also unique in that the use of the major persistent chemicals have been curtailed in the watershed by a variety of actions. Although it is likely the use of the chlorinated pesticides in agriculture was diminishing in the late 1960's, the Lake Michigan Enforcement Conference recommended regulatory actions on many uses in 1968. This recommendation led to restrictions on DDT in Illinois, Michigan and Wisconsin, including the sale of this compound. A more detailed summary is presented by Lueschow (1972).

The realization that the widespread use of PCB's has resulted in the widespread occurrence of these potentially hazardous chemicals in the environment moved Monsanto Company, the sole producer of PCB's in the United States, to restrict the sales of PCB's in 1970 and by April, 1971, only "close system" uses were able to purchase PCB's from Monsanto. However, there is no data to confirm the fact that PCB useages are significantly reduced.

As previously discussed, the FDA has placed a 5 ug/gm action level on PCB's in food for human consumption. Moreover, on March 18, 1972, this restriction was extended to food packaging materials. On May 2, 1972, the Environmental Protection Agency announced that all discharges to the aquatic environment involving PCB's will be restricted to the lowest possible level and that the desired limit will be 0.01 ug/l PCB's. These restrictions were re-enforced by the recommendation of the joint task force headed by the Council on Environmental Quality and the Office of Science and Technology (Task Force, 1972) which called for all current uses of PCB's, except capacitors and transformers, to be discontinued.

In summary, the use of chlorinated hydrocarbons in the agriculture and industry in the Lake Michigan watershed over the last few decades has resulted in the contamination of this valuable, mesotrophic body of water. Indirect evidence exists that these chemicals are having subtle detrimental effects on the species near the top of the food chain, and some of the food resources have been deemed unfit for human consumption. However, the Lake Michigan watershed has also realized unparalleled legislative action regarding the use of these hazardous, persistent chemicals in the last two years. The following sections

of this report summarize the activities of the States in the Lake Michigan watershed concerning PCB's and the results of its activities.

Table 1. The Comparative Toxicity of Eight Aroclors[a] (in µg/liter) to Daphnia magna in Lake Superior Water as Determined in Static Test Conditions

Aroclor	Three Week LC50	Confidence Limits[b]	Reproductive Impairment 50%	Confidence Limits	16%	Confidence Limits
1221	180	158-205	125	116-135	89	85.6-92.6
1232	72	62.6-82.8	66	60-72.6	53	50.5-55.7
1242	67	55.4-81	63	56.3-70.5	48	45.2-50.9
1248	25	21.4-29.2	24	21.2-27.1	16	13.9-18.4
1254	31	25.8-37.2	28	23.1-33.9	18	14.5-22.3
1260	36	27.7-46.8	33	27.5-39.6	22	17.7-27.3
1262	43	37-49.9	41	33-53.3	24	17.6-32.6
1268	253	222-288	206	185-228	162	146-179

[a]Polychlorinated Biphenyls: Aroclor 1221-1268.. Monsanto Chemical Company, St. Louis, Mo.

[b]Ninety-five percent confidence limits.

Programs Underway

Illinois

Water samples were collected routinely at four locations in 1971 and 1972. Two sewage treatment plants and two tributary sources were sampled during this period. The locations sampled were the Waukegan River, Pettibone Creek, North Shore Sanitary District plants at Waukegan and North Chicago. During 1971, thirty-seven sediment samples were collected at tributary streams, ravines, and offshore (within two miles) lake bed stations. Composite samples from fish were also analyzed during 1971 and 1972.

Indiana

In 1957, the State of Indiana initiated a water quality monitoring program. The original sampling network included two stations on Lake Michigan. At the present time, there are 16 sampling stations located on tributaries to Lake Michigan. In addition, five water treatment plant intakes on Lake Michigan are sampled as part of the program. This program provides data that are used to measure general characteristics of Indiana waters in the Lake Michigan Basin at important locations and to record trends in water quality.

The following table indicates the location and frequency of the routine sampling for PCB's:

Station	Type of Sample	Frequency
Lake Michigan-Hammond W.W.	grab	monthly
Lake Michigan-Whiting W.W.	grab	monthly
Lake Michigan-East Chicago W.W.	grab	monthly
Lake Michigan-Gary W.W.	grab	monthly
Lake Michigan-Mich. City W.W.	grab	monthly
Ind. Harbor Canal -Dickey Rd.	grab	monthly
Grant Calumet River-Indpls. Blvd.	grab	quarterly
Grant Calumet River-Kennedy Ave.	grab	quarterly
Burns Ditch-BD-1	grab	monthly
Burns Ditch-Portage Boat Yard	grab	quarterly
Burns Ditch-Chrisman Rd.	grab	quarterly
Trail Creek-Franklin St.	grab	monthly
St. Joseph River-Auten Rd.	grab	monthly
Elkhart River-at mouth	grab	quarterly

In addition to the regular water quality monitoring program, samples of the effluent from all municipal sewage treatment plants in the basin will be collected two times during 1973. When possible these samples will be composited over a 24-hour period.

This program will be expanded to include the collection of samples from various industrial outfalls and runoffs from landfalls. For the most part, these samples will be collected during comprehensive 24-hour surveys of point discharges which are routinely conducted in the Lake Michigan Basin.

Michigan

Michigan instituted a monitoring program for polychlorinated biphenyls (PCB's) early in 1971. The initial program consisted of a state-wide water sampling survey for determination of concentration in inland waters and tributaries to the Great Lakes. Supplementary sampling has since been conducted on stream sediments, municipal raw water intakes, groundwater drinking supplies, sanitary landfill runoffs, municipal wastewater treatment plants, industrial discharges, and fish from both inland and Great Lakes waters. Sampling is being continued on a periodic basis for establishment of trends.

Wisconsin

The Wisconsin Department of Natural Resources is surveying the waste effluents of some 55 communities in the Lake Michigan Basin. Those municipalities showing significant levels of toxic materials will be investigated to determine the source.

U.S. Bureau Sport Fisheries & Wildlife

Great Lakes Fishery Laboratory program of analysis for PCB's in Lake Michigan fish will continue with selected species of fish from two areas of Lake Michigan in 1973-74 according to the following schedule:

Time of Collection	Species	Collection Site	Number of Fish	Size Range	Years of Continuous Analysis
Spring	Chubs	Saugatuck	200	240-280 mm	2
Fall	Lake Trout	Saugatuck	30	500-800 mm	3
Fall	Chubs	Saugatuck	200	240-280 mm	5
Fall	Coho	Ludington	30	500-800 mm	6

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Lake Michigan programs related to Toxic Substances Committee.

	Program Description	Agency	Completed	Current	Pertinent Information
1.	Great Lakes Monitoring Program	US EPA - Region V Surveillance and Analysis Division		X	To give administrative guidance and coordination to the various US EPA activities.
2.	Water Quality Assessment Program on the Great Lakes - Northern Lake Michigan	Canada Center for Inland Waters	X		In 1972 completed 9 Great Lake cruises employing M/V Martin Karlsen to assess water quality.
3.	Program of analysis for polychlorinated biphenyls, DDT and dieldrin in Lake Michigan fish.	U.S. Bureau of Sport Fisheries and Wildlife, Great Lakes Fishery Laboratory		X	
4.	Toxic Substances Contamination Program: a. Metal b. PCBs c. Phthalates d. DDT and dieldrin	4 states: 1. Illinois 2. Indiana 3. Michigan 4. Wisconsin		1. X 2. X 3. X 4. X	Findings will be given in this Toxic Substances Report.
5.	Has a program for pollution detection, boat sewage, and HU-16 aircraft with infrared and ultraviolet scanner to detect pollution and physical processes.	U.S. Coast Guard		X	Pollution survey will include a 1000 mile district from Duluth, Mn. to St. Regis, N. Y.
6.	Programs include: Water Motion, Water Characteristics, Limnology, Lake Hydrology, and Limnology Systems.	Lake Survey Center - NOAA		X	Program consists of data collection investigations and studies.
7.	Under the Anadromous Fish Program research is directed toward the cause of die-off.	National Marine Fishery, Service (NMFS)		X	Studies include parasiticological, pathological, and pesticide residues
8.	Research program to include mathematical models to describe pollutants in the Great Lakes.	U.S. Geological Survey		X	Will use $S^{34}/_{32}$ ratio to describe pollution and circulation patterns
9.	Promotion of all aspects of Great Lakes research and dissemination of information.	International Association for Great Lakes Research		X	Has conferences annually.
10.	The Sea Grant Program in the Great Lakes area (Lake Michigan)	University of Wisconsin			
	Pesticide-Sediment Interaction on Green Bay	David Armstrong, Water Chemistry, UWSS		X	
	Aqueous Environmental Chemistry of Zinc in Lake Michigan	G. Fred Lee, Water Chemistry, UWSS		X	
	Pesticide Levels of Birds Wintering on Lake Michigan	Robert Ellarson, Wildlife Biology, UWSS		X	
	Uptake and Accumulation of Pollutants by Lake Michigan Fish	Mark Halaucon, Biochemistry, UWSS		X	
	Factors Affecting Energy Fixation in Lake Michigan	Alfred Beeton, Center for Great Lakes Studies, UWSS		X	
	A Comprehensive Study of the Water Quality of Milwaukee Harbor and Adjacent Lake Michigan	Alfred Beeton, Center for Great Lakes Studies, UWSS		X	
	Survey and Analysis of Milwaukee Harbor — Lake Michigan Exchange Rates	David Cutchin, Center for Great Lakes Studies, UWSS			
	Sediments as a Source or Sink of Nitrogen in Green Bay	D. R. Keeney, Soil Science, UWSS			
	Influence of Heated Effluent on the Distribution and Abundance of Fishes Near the Two Rivers and Kewaunee Nuclear Power Plants on Lake Michigan	John J. Magnuson, Zoology, UWSS			
11.	Lake Michigan Studies	University of Michigan		X	Employs a vessel to chemical biological and physical parameters. Also monitor air.
12.	Lake Michigan Studies	International Joint Commission (U.S. Section)		X	To supplement the Upper and Lower Great Lakes Studies to include PCBs, pesticides, phthalates and toxic metals.
13.	PCBs in 1971 Lake Michigan Fish	National Water Quality Laboratory C. Veith	X		Final report.

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Data Summary - Lake Michigan, Open Waters and Sediments

Illinois

	Aroclor (ppb) 1242 Mean	1242 Range	1254 Mean	1254 Range
Sediments (<1-3 miles offshore) 24 samples, 1971	23.7	(ND-106.1)	14.7	(2.5-46.9)

Indiana

	PCB (ppb) Mean	Range
Water Intakes 15 samples, 1973	0.02	(<.01 - 0.09)

Michigan

PCB concentrations in drinking water supplies from 45 intakes on the Great Lakes and connecting waters and an additional 20 on inland lakes and streams have generally been less than 0.01 ppb. Limited sampling of groundwater drinking supplies in southern Michigan has indicated that groundwater has not been significantly contaminated with PCB's.

Water Intakes	Date	Aroclor 1254 ppb
South Haven	3/9/71	<0.010
Holland	4/14/71	<0.010
Grand Rapids	4/14/71	<0.010
Muskegon	3/9/71	<0.010
Ludington	3/9/71	<0.010
Traverse City	3/2/71	<0.010
Escanaba	2/25/71	0.177
Gladstone	2/25/71	<0.010
Menominee	3/23/71	<0.010
Bridgeman	4/14/71	<0.010
Bridgeman	5/23/72	<0.010
St. Joseph	5/18/72	<0.010
Benton Harbor	5/18/72	<0.010
South Haven	5/18/72	<0.010
Holland	5/18/72	<0.010
Grand Rapids	5/18/72	<0.010
Muskegon	5/18/72	<0.010
Ludington	5/19/72	<0.010
Northport Point	6/21/72	<0.010
Traverse City	6/21/72	<0.010
Escanaba	8/28/72	<0.010
Gladstone	8/28/72	<0.010
Menominee	8/28/72	<0.010

Data Summary - Lake Michigan Fish

Illinois

Twenty-nine composite samples from five species of lake fish (yellow perch, chubs, carp, coho salmon, and alewives)were analyzed for PCB's in 1971. Concentrations in the composite samples ranged from 0.1 to 4.0 ppm with an average concentration of 2.1 ppm. The highest average concentrations of PCB's by sex and species were 0.4 ppm for yellow perch males, 3.4 ppm for chub males, 2.3 ppm both carp males and females, 2.2 ppm for coho salmon males and 3.1 ppm for alewife males. The concentrations were below the U.S. Food and Drug Administration's interim action level of 5 ppm.

In 1972, fourteen composite samples (69 individual fish) from two species of lake fish (yellow perch and chubs) were analyzed for PCB's. Concentrations in the composite samples ranged from 0.3 to 3.1 ppm with an average concentration of 1.7 ppm. The highest concentrations of PCB's were found in chub samples. Concentrations of 3.1 ppm were found in samples of female chubs. Samples of male chubs were similar with maximum values reaching 2.8 ppm. These concentrations were also below the FDA's interim action level.

Michigan

In 1972 Michigan developed a cooperative State-Federal study of contaminant levels in Great Lakes fish species including lake trout, salmon, whitefish, chubs, menominee, yellow perch, alewife, carp, and suckers. Fish from Lakes Michigan, Huron, Erie, and Superior are systematically being sampled on an annual basis to obtain information on areas where contaminants approach or exceed FDA guidelines for consumer protection. The project, developed by the State agencies in cooperation with the U.S. Food and Drug Administration and the Bureau of Sport Fisheries and Wildlife Great Lake Laboratory, will establish patterns of residues of mercury, PCB's, DDT and dieldrin in Great Lakes fish. The following table shows the concentrations of PCB's detected in fish from Lake Michigan during the first year of this study. PCB's in Salmonids (lake trout, steelhead, coho salmon, and chinook salmon) and chubs were shown to exceed the FDA guideline of 5.0 ppm while concentrations in other species did not exceed this guideline.

Fish Cont'd

Concentrations of polychlorinated biphenyls (PCB's) found in fish species taken from Michigan waters of Lake Michigan during 1972*.

Species	PCB's by District** in ppm (sample size in parenthesis) MM3	MM4	MM5	MM6	MM7	MM8	Total # Fish Sampled	Mean Concentration
Alewife	1.7 (3)			2.3 (1)	2.7 (6)	2.7 (6)	16	2.4 ± 0.6
Carp					3.9 (6)		6	3.9 ± 2.0
Chub				3.2 (2)	8.5 (8)	6.5 (9)	19	7.0 ± 4.2
Menominee				0.8 (1)	1.2 (2)		3	1.1
Perch				0.5 (1)	0.4 (5)	0.5 (11)	17	0.4 ± 0.4
Coho Salmon			11.2 (3)				3	11.2
Chinook Salmon				12.4 (10)			10	12.4 ± 5.0
Suckers	0.8 (6)			0.7 (2)	1.5 (3)	1.1 (6)	17	1.0 ± 0.7
Steelhead			6.0 (2)				2	6.0
Lake Trout	11.1 (3)	6.4 (3)		3.2 (2)	5.7 (6)	9.2 (6)	20	7.4 ± 4.0
Whitefish		0.6 (3)		0.8 (2)	1.1 (1)		6	0.7 ± 0.3

* Data from Michigan's Great Lakes Environmental Contaminant Survey, 1972.
** Zones of Lake Michigan within Michigan Boundaries
MM3 - Northern Basin
MM4 - Grand Traverse Bay
MM5 & MM6 - Central Basin
MM7 & MM8 - Southern Basin

Fish Cont'd

U.S. BF&W

Polychlorinated Biphenyl

Approximately 800 of the fish collected from Lake Michigan were analyzed for PCB mixtures resembling that of Aroclor 1254. A generalized summary of these results is presented in the accompanying table in which the range and average concentrations of PCB's (as Aroclor 1254) is reported for 13 species of fish. The mean concentrations ranged from 2.1 ug/gm in smelt to 15 ug/gm in chinook salmon. The data show that the larger fish such as brown, lake and rainbow trout and chinook and coho salmon contained PCB's at concentrations two to three times the 5 ug/gm action level established by the FDA. The mean PCB concentrations in suckers, smelt and whitefish were considerably less than 5 ug/gm and the mean concentrations in the alewife, carp, chub and perch were approximately 5 ug/gm, ranging from 4.7 to 5.9 ug/gm. As is expected, the larger fish with greater percentage fat contain greater concentrations of PCB's.

Summary of PCB Concentrations in the 1971 Lake Michigan Fish

Species	Number of Fish Analyzed	Concentration of PCB (ug/gm as Aroclor 1254) Range[a]	Mean[b]
Alewife	76	2.5 - 8.9	4.7
Brown Trout	16	6.7 - 12	8.8
Carp	42	1.7 - 11	5.5
Chub	229	3.4 - 8.1	5.3
Chinook Salmon	21	9.9 - 24	15
Coho Salmon	56	3.6 - 17	12
Lake Trout	157	8.1 - 21	14
Perch	48	4.2 - 11	5.9
Rainbow Trout	10	8.8 - 12	10
Red Sucker	16	2.7 - 3.2	2.9
Smelt	35	0.7 - 3.2	2.1
White Sucker	50	2.1 - 11	4.1
Whitefish	43	1.5 - 6.1	3.5

[a] indicates range of averaged level of PCB of a given species at a given sampling location--weight wet basis

[b] average of all locations sampled

Fish Cont'd

Not only does the PCB concentration vary considerably among the 13 species captured, but also the range of concentrations in a single species in the lake was generally greater than 100 percent (the range in red suckers was less; however, all were captured in the same region). Although some variation in concentration is expected because of the normal analytical precision, the table reveals much larger ranges which are undoubtedly due to other factors which limit the usefulness of mean concentrations presented. Previous research has shown (Reinert, 1970) that the lipid content, size of fish, season of capture and concentration in the water may effect the observed concentration of chlorinated hydrocarbons in tissue considerably. Accordingly, the data in the table must be considered in more detail.

The concentration of PCB's in alewives (on a fresh weight basis) were greater in southern Lake Michigan than in the northern regions, although anomolies are apparent. It is apparent that most of the alewives captured south of a line between Saugatuck and Sheboygan contained between 4.4 and 5.5 ug/gm PCB's whereas those caught north of the line contained between 3.5 and 4.4 ug/gm. An interesting exception is the high concentration, 8.9 ug/gm, in the alewives from Rock Island just off the Door County Peninsula in Wisconsin.

The analyses of brown trout suggested similar trends in that those from Michigan City at the southern end of the lake contained 11.9 ug/gm while those from Sheboygan and Gills Rock contained 7.9 and 6.7 ug/gm, respectively.

The carp from Michigan City also had higher levels of PCB's than did those from the northern region. In contrast to the 11.0 ug/gm found in the Michigan City carp, those from Saugatuck and Sheboygan contained 4.6 and 1.7 ug/gm, respectively.

The PCB's in chubs in southern Lake Michigan ranged from 4.9 ug/gm near Milwaukee to 8.1 ug/gm near Saugatuck. In general, the chubs from the northern regions were below 5 ug/gm. The concentration of PCB's in the five groups of chubs collected over three months near Sheboygan varied without trend between 3.7 and 6.1 ug/gm, although the mean was below 5 ug/gm. The variation is somewhat less when the data is expressed on a lipid basis. For example, the PCB's in the 8/27 and 10/15 chubs was 5.0 and 3.7 ug/gm--wet weight, respectively. In contrast, the concentration of PCB's in the lipids was 23 ug/gm and 21 ug/gm, respectively. Thus, much of the observed variability is due to lipid content of the fish analyzed.

One hundred percent of the chinook salmon captured in Wisconsin contained greater than 5 ug/gm PCB's and mean concentrations ranged from 24 ug/gm in Milwaukee to 9.9 ug/gm in Strawberry Creek.

Little trend in the concentration of PCB's in coho salmon was observed with sampling region. With the exception of coho caught early in 1971 near Michigan City, the mean concentration of PCB's ranged from 11 ug/gm in those near Ludington to 14 ug/gm in those near Michigan City.

Fish Cont'd

The PCB's in lake trout were most concentrated in the trout from Michigan City, Saugatuck and Milwaukee where mean concentrations were generally between 15 and 22 ug/gm. The trout from the northern areas such as Sheboygan, Ludington, Grand Traverse Bay and Gill's Rock were considerably lower, and the mean concentrations ranged between 8 and 15 ug/gm.

The concentration of PCB's were unexpectedly high in the perch caught near Milwaukee in that the mean of the 10 fish was 11 ug/gm. In contrast, perch from other regions appear to be less by a factor of two, and those from lower Green Bay contained only 2.7 ug/gm.

Rainbow trout were only caught near Michigan City and Gill's Rock. The Michigan City trout had 12 ug/gm PCB's while those from Gill's Rock averaged only 8.8 ug/gm PCB's.

The concentration of PCB's in suckers and smelt were generally between 2 and 4 ug/gm, although the average concentration in the three white suckers from Saugatuck was 6.0 ug/gm. With the exception of whitefish caught at Grand Haven and Michigan City, the PCB concentration in whitefish was less than 3 ug/gm.

Additional Data from U.S. BSFSL Great Lakes Fishery Laboratory

Mean PCB Levels in Lake Michigan Fish

Species	Time of Collection	Location of Collection	Number of Analysis	Number of Fish	Mean Length (cm)	Mean Weight (grams)	Mean Lipids (percent)	Total PCB's (ppm)
Lake Trout	Fall, 1971	Gd. Traverse Bay	3	15	647	3,038	N.M.①	14.3
Lake Trout	Fall, 1972	Saugatuck, MI.	20	20	688	3,199	18.5	20.7
Coho	Fall, 1972	Ludington, MI.	10	10	D.A.②	D.A.②	7.3	10.9
Whitefish	Fall, 1971	Gd. Traverse Bay	3	15	505	1,390	N.M.①	2.2
Bloater Chub	Spring, 1972	Saugatuck, MI.	20	200	256	160	16.8	8.0
Bloater Chub	Fall, 1972	Saugatuck, MI.	12	120	255	177	21.6	5.7
Bloater Chub	Fall, 1972	Saugatuck, MI.	8	80	229	120	15.8	3.6

① N.M. = not measured

② D.A. = data available

MONS 204004

Data Summary - Tributaries

Illinois

	Aroclor (ppb) 1242		1254	
	Mean	Range	Mean	Range
Tributaries				
4 water samples, 1971	0.712	(0.140-1.810)	0.258	(0.192-0.383)
13 water samples, 1972	0.110	(ND - 0.653)	0.158	(0.033-0.841)
Sediments				
13 samples from ravines and minor tributaries, 1971	95.8	(ND - 55.30)	32.3	(1.5-232.0)

Indiana

	PCB (ppb)	
	Mean	Range
Tributaries		
6 water samples, 1973	.025	(<.01 - .07)

MONS 204005

Tribs. Cont'd

Michigan

Quarterly water sampling in thirty Michigan tributaries showed that about 60 percent of the samples contained more than 0.01 ppb with one stream, the Saginaw River, having a high concentration of 2.9 ppb. Fish from the Saginaw River had PCB concentrations as high as 165 ppm. Five Michigan streams had mean concentrations in water samples over 0.10 ppb. These were all located in the populous southeastern lower peninsula which drains into lower Lake Huron, Lake St. Clair and Lake Erie. Of the Lake Michigan streams, the Grand and Kalamazoo rivers consistently showed the highest concentrations with means of 0.041 and 0.065 ppb, respectively.

A study of transport of PCB's to Lake Michigan on suspended solids was conducted during March-May, 1973, on the Grand, Kalamazoo and St. Joseph Rivers. Sediment traps were suspended 1-2 meters off the bottom of the rivers and collected at varying time intervals in each river ranging from 3 times weekly to once a month. Concentrations of PCB's were notably higher in the settleable solids from the Kalamazoo River than from the Grand and St. Joseph rivers. The over-all mean for all samples were 3.52, 0.99 and 0.97 ppm (oven-dry basis) for the Kalamazoo, Grand and St. Joseph Rivers, respectively. This data substantiates earlier results indicating elevated levels of PCB's in the Kalamazoo River watershed. Extensive sampling at upstream sections of the watershed has identified past and present wastepaper recycling by paper industries located in the City of Kalamazoo as the major source of contamination to the river. Certain sediment deposits in impoundments on Portage Creek, a tributary to the Kalamazoo River at Kalamazoo, were found to contain PCB's at concentrations exceeding 350 ppm (dry weight basis). Leaching from these PCB enriched sediments appears to be significant. Fish collected immediately downstream from the City of Kalamazoo were found to contain residues of PCB's in their tissue as high as 110 ppm (Hesse and Willson, 1972).

An example of one location in Michigan where monitoring and subsequent control measures have resulted in a marked reduction in PCB contamination is the Saginaw River basin. Even though it is not within the Lake Michigan watershed, the Saginaw River PCB situation is worthy of review. Monitoring of major Great Lakes tributaries during 1971-1972 identified the Saginaw River as having the highest concentrations of PCB's of any tributary within Michigan boundaries. Intensive sampling throughout the river basin in search of point sources successfully isolated ten major points of PCB discharge to the river system. Each of the industrial sources were asked to identify the cause of their losses and to take corrective action. Control measures, in most cases, conversion to non-PCB containing products, have proved very effective toward lowering the PCB concentrations in the Saginaw River. A sharp PCB decline at a monitoring site near the river mouth was observed in October, 1972, and concentrations have remained low since that date. It is hoped that a corresponding decline in PCB concentrations in fish from the river and Saginaw Bay will soon be observed.

Mean PCB Concentrations in Michigan Tributaries to the Great Lakes in 1971-72.

Lake Basin	River	PCB's (ppb as 1254)	Range (ppb as 1254)
Michigan	St. Joseph	0.013	<0.010-0.0[illegible]
	Kalamazoo	0.055	0.019-0.[illegible]
	Grand	0.041	0.011-0.[illegible]
	Muskegon	0.010	<0.010-0.[illegible]
	Manistee	0.016	<0.010-0.[illegible]
	Boardman	0.017	<0.010-0.[illegible]
	Elk	0.012	<0.010-0.[illegible]
Huron	Saginaw	1.100	0.650-2.[illegible]
	Cass[1]	0.014	<0.010-0.[illegible]
	Flint[1]	0.078	0.010-0.[illegible]
	Shiawassee[1]	0.029	<0.010-0.[illegible]
	Tittabawassee[1]	0.140	<0.072-0.[illegible]
	Au Sable	<0.010	<0.010-0.[illegible]
	Thunder Bay	0.023	<0.010-0.[illegible]
	Cheboygan	0.032	<0.010-0.053
St. Clair	Clinton	0.160	<0.039-0.430
	Black	0.043	<0.010-0.110
	St. Clair	0.010	<0.010-0.[illegible]
Erie	Raisin	0.210	<0.010-0.[illegible]
	Huron	0.012	<0.010-0.[illegible]
	Rouge[2]	0.470	0.058-1.[illegible]
	Detroit	0.020	<0.010-0.053

[1] Tributary to Saginaw River
[2] Tributary to Detroit River downstream from Detroit River sampling station

Concentrations of PCB's (polychlorinated biphenyls) in the settleable solids collected from the mouths of the Grand, Kalamazoo, and St. Joseph Rivers; Spring 1973, for comparison of variable sampling periods. Concentrations in ppm on an oven-dry basis.

River	Sample Type [a]	Sample Dates 3/21	3/23	3/30	4/2	4/4	4/6	4/9	4/11	4/13	4/20	4/27	4/30	5/2	5/4	5/11	Means
Grand	3X	3.24			1.6*	0.95	1.0	<0.1	0.93	1.58			0.83	3.5	0.53		1.43
	Weekly		1.25	0.94			1.1			1.00	0.56	0.74			0.00	0.77	0.89
	Biweekly			0.85						0.73		0.60				0.60	0.67
	Monthly									1.41						0.50	0.96
															Mean		0.99
Kalamazoo	3X	6.7	27.5		2.08	<0.1	2.52	1.33	3.20	<0.1			3.11	3.59	3.75		4.72
	Weekly		6.83	2.0			3.54			3.77	3.09	2.90			2.63	4.67	3.87
	Biweekly			3.77						2.64		2.64				2.50	2.86
	Monthly									2.11						3.13	2.63
															Mean		3.52
St. Joseph	3X								2.13	0.68		0.95	0.63	0.17			0.73
	Weekly									0.85		0.75		0.13	1.21		1.16
	Biweekly											0.67			0.95		1.24
	Monthly														0.63		0.75
															Mean		0.97

[a] 3X = Sample collected Mon, Wed, and Friday
* Concentration based upon a 1:1 ratio of Aroclor 1242 and 1251. All other concentrations calculated as Aroclor 1242.

Tribs. Cont'd

Polychlorinated biphenyls (PCB's) in composite water samples from the Saginaw River at Bay Harbor Marina, March 1971 - May 1973.

Collection Date	Concentration in parts per billion
3-9-71	0.450
6-10-71	0.550
8-27-71	2.900
10-26-71	1.100
6-8-72	0.640
10-13-72	0.360
10-29-72	<0.020
10-30-72	<0.020
11-1-72	0.091
11-2-72	0.031
11-4-72	<0.020
11-6-72	0.022
1-26-73	<0.100
5-24-73	0.210

Concentrations of poly-chlorinated biphenyls (PCB's) in fish from Saginaw River, December 7, 1971. (ppm; wet weight).

Species	Location	Length	Percent fat	PCB's based upon 1242 standard
Perch	Zero-Hemlock Discharge Channel	9.0	1.3	86.3
Carp	" " " "	21.0	0.9	8.0
Catfish	" " " "	8.0	3.0	37.1
Catfish	" " " "	7.5	4.9	47.9
Carp	U.S. Coast Guard Station	23.0	—	48.0
Carp	" " " "	24.0	30.5	20.4
Carp	" " " "	20.6	6.5	15.5
Carp	" " " "	26.0	5.9	45.0
Carp	" " " "	21.0	4.6	30.7
Pike	" " " "	27.0	1.6	36.6
Pike	" " " "	23.0	1.1	6.9
Gizzard Shad	" " " "	14.0	17.5	865.1
Gizzard Shad*	" " " "	6.0	35.3	32.5
Gizzard Shad*	" " " "	4.5	35.0	161.9
Gizzard Shad*	" " " "	5.0	17.0	77.0
Gizzard Shad*	Milwaukee Bridge	4.5	15.7	24.1
Gizzard Shad*	" "	5.0	9.6	57.0
Gizzard Shad*	" "	5.0	8.7	30.4

* Concentration based upon analysis of whole fish. All others based upon edible portion only.

MONS 204008

Data Summary - Discharges

Illinois

	Aroclor (ppb) 1242		1254	
	Mean	Range	Mean	Range
Sewage Treatment Plants				
6 samples, 1971	1.443	(0.268-4.020)	0.300	(0.139-0.568)
16 samples, 1972	0.177	(ND-0.510)	0.126	(0.055-0.200)

Indiana

Municipality	Date	Flow (MGD)	Aroclor 1254 (ppb)
Michigan City	11/27 & 28/72	11.0	2.46
Michigan City	12/20 & 21/72	13.3	0.19
Valparaiso	11/27 & 28/72	4.0	0.27
Valparaiso	12/20 & 21/72	4.0	0.20
Hobart	11/27 & 28/72	2.7	0.35
Hobart	12/20 & 21/72	3.1	0.11
Hammond	11/27 & 28/72	42.9	<0.10
Hammond	12/20 & 21/72	42.3	<0.10
East Chicago	11/27 & 28/72	18.5	<0.10
East Chicago	12/20 & 21/72	18.7	0.10
Chesterton	11/27 & 28/72	1.5	<0.10
Chesterton	12/20 & 21/72	1.8	<0.10
Gary	11/27 & 28/72	50.5	0.38
South Bend	3/22 & 23/73	35.8	<0.10
Mishawaka	3/22 & 23/73	10.39	0.13
Elkhart	3/22 & 23/73	17.5	<0.10
Goshen	3/22 & 23/73	4.8	<0.10
Nappanee	3/22 & 23/73	.900	<0.10
Kendallville	2/28/73	1.2	<0.10
LaGrange	3/7/73	.185	<0.10
Ligonier	3/7/73	.434	<0.10
Angola	3/7/73	.784	0.17
Syracuse	3/7/73	.305	0.13

Discharges Cont'd

Michigan

Analyses of surface water runoff from sanitary and industrial landfills in Michigan suggest that these are a minor source of environmental contamination. Five of the 9 samples collected had PCB concentrations ranging from 0.04 to 0.30 ppb while the others contained less than 0.01 ppb.

Sampling of municipal wastewater treatment plant (WWTP) effluents throughout Michigan in 1971 and 1972 indicated that many WWTP's represent major point sources of PCB loss to surface waters of the State. The average PCB concentration of 60 effluents sampled was 2.55 ppb. While only seven of the WWTP effluents exceeded 1 ppb, the Bay City WWTP located on the Saginaw River had an average effluent concentration of 120 ppb (high of 340 ppb), skewing the over-all average for all plants sharply upward. The average concentration excluding the Bay City WWTP was 0.56 ppb. Those WWTP's with PCB concentrations in effluents exceeding 1 ppb were, with one exception, located on rivers already identified as having high levels of PCB contamination. Sampling of 58 WWTP effluents in 1973 continues to show high PCB levels with an average concentration of 0.52 ppb, including the Bay City plant. The PCB discharge from the Bay City WWTP has been greatly reduced as a result of control measures in industries served by the WWTP.

Sampling of sewage sludge from 57 of the 58 WWTP's tested in 1973 showed Bay City to have the highest concentration of PCB's in the sludge being removed by the treatment process. The PCB concentration in the sludge from the Bay City plant was 352 ppm (dry weight basis) compared to a state-wide average of 15.6 ppm.

In an attempt to identify major contributors of PCB's within municipal WWTP systems, sampling at key points in the interceptor systems has been conducted within the municipalities of Bay City, Mt. Clemens, Saginaw, Adrian, Detroit and Kalamazoo. This program has been very successful. The City of Detroit has, in fact, established an on-going sampling program within their interceptor system with analytical assistance from the State. They are applying a new City of Detroit sewer ordinance which limits discharges within the wastewater system to a maximum of 0.1 ppb.

A broad scale sampling of industrial discharges throughout Michigan has shown results indicative of the widespread usage of PCB's. Nearly half of the industrial discharges sampled have contained more than 0.1 ppb with many in excess of 1 ppb. The highest concentration detected in an industrial discharge in Michigan has been 7,200 ppb. Automotive plants, chemical companies, and paper product manufacturers are among the types of industries with highest concentrations. Also industries and building complexes, including some schools and hospitals, with heat transfer systems appear to be another major source. Industries identified as sources of PCB pollution have been encouraged to changeover to replacement compounds or to clean up their operation so that discharges of PCB's do not exceed the present Michigan guideline of 0.1 parts per billion.

Michigan is currently trying to get a handle on losses from electrical transformers in leakage, servicing, and replacement within plants. It

Discharges Cont'd

appears that many of the small transformer maintenance companies are still dumping PCB's down the drain rather than returning them for incineration.

Dischargers Cont'd

Polychlorinated Biphenyls (PCB's) in Effluents of Municipal Wastewater Treatment Plants throughout Michigan 1971-1972. Unless specified, all samples are 8 hr. composites.

CITY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
Adrian	3-30-72	1.80	4.60
	6-13-72	14.00	
	6-14-72	6.90	
	9-6-72	0.41	
Albion	3-28-72	0.44	0.44
Ann Arbor	10-14-71	0.14	0.12
	3-30-72	<0.10	
Battle Creek	10-5-71	0.39	0.39
	3-28-72	0.16	
	2-21-72	0.92	
	6-6-72	0.28	
	6-7-72	0.21	
Bay City	11-4-71	340.00	120.00
	11-22-71	210.00	
	11-23-71	60.00	
	3-2-72[a]	290.00	
	4-4-72	19.00	
	6-13-72	11.00	
	6-14-72	25.00	
	9-14-72	5.70*	
Denton Harbor - St. Joseph	10-28-71	0.99	0.65
	4-4-72	0.31	
Brighton	10-5-71	0.38	0.38
Charlotte	7-20-72	0.61	0.61
Constantine	4-4-71	0.85	0.85
Detroit	10-14-71	2.20	1.95
	12-20-72[c]	3.00	
	1-20-72	0.92	
	3-9-72	2.40	
	4-17-72[b]	1.80	
	6-1-72	0.88	
	10-19-72	2.50**	
Dexter	10-14-71	<0.10	0.10

Dischargers Cont'd

CITY	DATE	PCB's Aroclor 1254 (ppb)	Mean Conc. (ppb)
E. Lansing	11-15-71	0.69	0.51
	4-3-71	0.35	
Escanaba	12-16-71	0.29	0.29
Essexville	11-4-71	0.21	0.24
	3-31-72	0.28	
Flint	10-5-71	1.30	0.68
	3-31-72	0.92	
	6-7-72	0.47	
	6-8-72	0.30	
	10-5-72	< 0.10	
Flushing	10-5-72	0.52	0.52
Gladstone	7-21-72	0.19	0.19
Grand Haven	4-4-72	< 0.50	< 0.50
Grand Rapids	11-15-71	0.37	0.52
	3-30-72	0.68	
Holland	10-20-71	0.79	0.60
	3-29-72	0.42	
Houghton-Hancock	3-21-72	< 0.10	0.10
Iron Mountain-Kingsford	3-21-72	0.55	0.87
	4-4-72	1.20	
Ironwood	3-20-72	0.16	0.16
Jackson	11-16-71	<0.10	<0.10
	2-21-72	<0.10	
	3-28-72	<0.10	
Kalamazoo	10-5-71	1.30	0.66
	3-28-72	0.83	
	6-6-72	0.48	
	6-7-72	0.53	
	12-6-72	0.19[e]	
L'Anse	4-21-72	<0.10	<0.10
Lansing	10-7-71	0.23	0.18
	4-4-72	0.13	

Dischargers Cont'd

CITY	DATE	PCB/s Aroclor 1254 (ppb)	Mean Conc. (ppb)
Manistique	12-15-72	<0.20	<0.20
Marquette	12-14-71	0.35	0.35
Marshall	3-28-72	<0.10	<0.10
Menominee	12-15-71	0.35	0.35
Midland	2-2-72	0.29	0.23
	3-31-72	0.40	
	4-14-72	0.13	
	10-2-72[d]	0.13	
Milford	10-14-71	<0.10	<0.10
Monroe	11-15-71	0.60	0.46
	3-30-72	0.33	
Mt. Clemens	11-15-71	1.40	5.21
	3-30-72	2.90	
	6-7-72[c]	4.50	
	6-8-72[c]	3.10	
	7-26-72	9.40	
	8-2-72	10.00	
Mt. Pleasant	3-31-72	<0.10	<0.10
Muskegon	11-15-71[c]	0.28	0.28
Muskegon Heights	11-15-71[c]	0.37	0.37
Niles	4-4-72	0.68	0.68
Norway	4-5-72	0.40	0.40
Ontonagon	4-21-72	<0.10	<0.10
Owosso	9-14-72	<0.10	<0.10
Parchment	4-20-72	<0.10	<0.10
Pontiac (Auburn Rd.)	11-17-71	<0.10	0.35
	3-30-72	0.61	
Pontiac (E. Blvd.)	11-17-71	0.20	0.45
	3-30-72	1.30	
	6-6-72	0.15	
	6-7-72	0.16	
Portage	11-15-71[d]	1.90	1.90

Dischargers Cont'd

CITY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
Port Huron	11-15-71	0.28	0.40
	3-30-72	0.52	
Saginaw	10-6-71	1.10	1.80
	3-31-72	3.80	
	6-7-72	2.00	
	6-8-72	1.50	
	10-4-72[d]	0.74	
St. Ignace	12-15-72	<0.20	<0.20
South Haven	4-4-72	<0.10	<0.10
Swartz Creek	10-5-72	<0.10	<0.10
Three Rivers	4-4-72	<0.30	<0.30
Trenton	11-16-71	0.14	0.53
	3-30-72	1.10	
	6-6-72	0.47	
	6-7-72	0.91[e]	
Warren	11-15-71	0.16	0.13
	3-30-72	0.10	
Wayne County (Wyandotte)	11-16-71	0.64	0.40
	3-30-72	0.17	
White Pine	4-21-72	0.2	0.20
Wyoming	11-30-72[c]	0.44	0.49
	3-30-72	0.55	
Ypsilanti	11-16-71	0.22	0.21
	4-2-72	0.21	
Ypsilanti Twp #1	11-16-71	0.12	0.11
	4-2-72	<0.10	
Ypsilanti Twp #2	11-16-71	0.19	0.17
	4-2-72	0.16	

*Aroclor 1242 Standard
**Aroclor 1242 and 1254 in 1:1 ratio

[a]6 hr [b]10 hr [c]24 hr [d]Grab [e]hexane lost GRAND MEAN 2.55

Dischargers Cont'd

Concentrations of PCB's in the Final Effluent from Wastewater Treatment Plants throughout Michigan, Spring, 1973. Concentrations in parts per billion dry weight.

CITY	DATE	PCB's		
		1242	1254	1242:1254
Adrian	3/7			0.26
Albion	2/22		0.34	
Ann Arbor	3/1		0.25	
Bay City	3/1	3.20		
Battle Creek	2/28		<0.10	
Benton Harbor-St. Joseph	2/28		0.20	
Brighton	3/1			0.33
Cadillac	3/28		0.53	
Charlotte	5/1		0.34	
Constantine	2/28		0.46	
Detroit	2/28	2.15		
Dexter	3/1		0.23	
East Lansing	5/2		0.18	
Escanaba	3/28			0.28
Essexville	3/1		0.10	
Flint	2/22		<0.10	
Gladstone	3/28		0.44	
Grand Haven	2/21		<0.10	
Grand Rapids	2/21		1.05	
Holland	2/21		<0.10	
Houghton-Hancock	3/27		0.18	
Iron Mountain-Kingsford	3/28		0.69	
Ironwood	3/27			0.29
Jackson	2/22		<0.1	
Kalamazoo	2/29			1.12
L'Anse	3/27			0.31
Lansing	4/18		0.22	
Manistique	3/28		0.63	
Marquette	3/27		0.29	
Marshall	2/22		0.15	
Menominee	2/28		0.57	
Midland	3/1		<0.10	
Milford	3/8			2.20
Monroe	5/4		<0.10	
Mt. Clemens	3/8			2.90
Mt. Pleasant	3/28		0.29	
Muskegon	2/28		0.88	
Muskegon Heights	2/28		0.14	
Niles	2/20		0.68	
Norway	3/28		<0.10	
Owosso	2/21		0.12	
Pontiac (Auburn)	3/12			0.60
Pontiac (E. Blvd.)	3/12			0.54
Port Huron	3/8			1.80
Saginaw	3/1			0.77
Sault Ste. Marie	3/28		0.73	

Dischargers Cont'd

CITY	DATE	PCB's		
		1242	1251	1242:1251
St. Ignace	3/28		0.31	
Three Rivers	2/21		<0.10	
Traverse City	3/7		<0.10	
Trenton	2/28		<0.10	
Warren	2/27		<0.10	
Wayne County	2/28		0.40	
Wyoming	2/21		0.22	
Ypsilanti	2/28			0.31
Ypsilanti Twp #1	3/1		<0.10	
Ypsilanti Twp #2	3/1		<0.10	

*Concentrations based on best fit of 3 standards: Aroclor 1242, Aroclor 1254, or a mixture of Aroclor 1242 and 1254 in a 1:1 ratio.

Dischargers Cont'd

Concentrations of PCB's in the sludge from fifty-seven municipal wastewater treatment plants in Michigan, Spring 1973. Concentrations in parts per million, dry weight.

City	Date	PCB's* 1242	1254	1242:1254
Adrian	3/ 7			24.0
Albion	2/22		1.5	
Ann Arbor	3/1		1.1	
Bay City	3/1	352.0		
Battle Creek	2/28		2.8	
Benton Harbor-St. Joseph	2/28		13.8	
Brighton	3/1		<0.1	
Cadillac	3/28		<0.1	
Charlotte	5/1		6.8	
Constantine	2/28		2.1	
Detroit	2/28	32.1		
Dexter	3/1		3.2	
E. Lansing	5/2		4.6	
Escanaba	3/28		5.9	
Essexville	3/1		3.9	
Flint	2/22		6.3	
Gladstone	3/28		4.1	
Grand Haven	2/21		4.1	
Grand Rapids	2/21		11.8	
Holland	2/21		0.8	
Howell	4/26		15.0	
Houghton-Hancock	3/27		5.5	

Dischargers Cont'd

City	Date	PCB's 1242	1254	1242:1254
Iron Mountain - Kingsford	3/28		9.5	
Ironwood	3/27		5.2	
Jackson	2/22		3.0	
Kalamazoo	2/29	23.3		
L'Anse	3/27		4.4	
Lansing	4/18		5.3	
Manistique	3/28		1.5	
Marquette	3/27		2.8	
Marshall	2/22		3.9	
Menominee	2/28		4.2	
Midland	3/1		2.3	
Milford	3/8			50.5
Monroe	5/4		3.3	
Mt. Clemens	3/8	175.0		
Mt. Pleasant	3/28		6.5	
Muskegon	2/28		102.7	
Muskegon Heights	2/28		11.0	
Niles	2/20		7.3	
Norway	3/28		<0.1	
Owosso	2/21		2.0	
Pontiac (Auburn)	3/12			12.1
Pontiac (E. Blvd.)	3/12			9.2
Port Huron	3/8			9.2

Dischargers Cont'd

City	Date	PCB's 1242	1254	1242:1254
Saginaw	3/1		5.0	
Sault Ste. Marie	3/28		2.4	
St. Ignace	3/28		1.5	
Three Rivers	2/21		4.1	
Traverse City	3/7		1.8	
Trenton	3/28		<0.1	
Warren	2/27		<0.1	
Wayne County	2/28	2.0		
Wyoming	2/21		0.58	
Ypsilanti	2/28		2.0	
Ypsilanti Twp. #1	3/1		<0.1	
Ypsilanti Twp #2	3/1		<0.1	

* Concentration based on best fit of 3 standards: Aroclor 1242, Aroclor 1254, or a mixture of Aroclor 1242 and 1254 in a 1:1 ratio.

Dischargers Cont'd

Wisconsin - 1973 Survey Results

Municipality	PCB Conc. ppb	PCB Lbs.
Adell	.33	.000058
Algoma	<.05	-------
Amherst	<.05	-------
Appleton	.26	.010
Buttes Des Mortes Utility Dist.	.11	.00019

Bear Creek	<.05	-------
Berlin	<.05	-------
Birnamwood	.28	-------
Bonduel	<.05	-------
Brillion	.5	.00066
Bristol	<.05	-------
Brookfield	<.05	-------
Cedar Grove	<.1	-------
Chilton	1.45	.032
Clintonville	<.05	-------
Coleman	.1	.000021
Crivitz	<.05	-------
Depere	.31	-------
Elkhart Lake	<.1	-------
Fond du Lac	.59	.032
Grafton	<.05	-------
Green Bay	.44	.067
Kenosha	<.05	-------
Marinette	<.05	-------
Neenah-Menasha	2.1	.074
Milwaukee-South Shore	1.1	.068
North Fond du Lac	.23	.00053
Racine	.34	.021
Shawano	.4	.0044
Sheboygan	17	.34
Suring	.21	.000059
Waldo	.23	.000038
West Bend	.19	.0018

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MAY 28 1974

POLYCHLORINATED BIPHENYLS IN EFFLUENTS FROM SEWAGE TREATMENT PLANTS IN SOUTHEASTERN WISCONSIN

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ABSTRACT

The Wisconsin Department of Natural Resources and the State Laboratory of Hygiene conducted a survey of polychlorinated biphenyl (PCB) concentrations in 11 municipal sewage treatment plants in southeastern Wisconsin. Samples were collected 4 times over a one-year period and follow-up sampling was done at 12 and 14 months later.

The polychlorinated biphenyl found at 10 of the 11 sewage treatment plants was Aroclor 1254 at concentrations from 0.05 µg/l (determinable limit) to 2.8 µg/l. Effluents from the eleventh treatment plant contained Aroclor 1248 at concentrations as high as 42 µg/l. Mass transport of Aroclor 1254 varied from 2.4×10^{-4} to 1.42×10^{-1} pounds per day.

One sewage treatment plant was studied for 24 hours on a 2-hour sampling schedule. Samples were taken from raw sewage influent, final effluent, trickling filter effluent, primary sludges and digester sludges. The concentration in the influent varied from 0.1 to 3.1 µg/l. The sludges were found to contain PCB concentrations that were 1,000 times higher than those found in the fluid wastes. The sewage plant was removing 70 percent of the polychlorinated biphenyls from the influent.

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INTRODUCTION

Chlorinated hydrocarbons are synthetic organic chemicals which have been found to be widespread contaminants in the aquatic environment. These contaminants enter the aquatic environment as runoff from agricultural and municipal applications and waste from industrial practices.

In the past six years, the presence of pesticides in the environment has stimulated increasing study and concern. The concern over pesticides is based on possible acute and chronic toxicities, particularly reproductive failure in birds and animals. As methods of detection were improved, polychlorinated biphenyls (PCB's) (mixtures of chlorinated biphenyl compounds, having various percentages of chlorination) were found along with certain pesticides. Interest in PCB's increased because some of the physiological effects of the PCB isomers were similar to those of the chlorinated pesticides.

In Wisconsin, Veith *(7)* found PCB's in samples taken from the Milwaukee River near Milwaukee, Wisconsin. Concentrations of this PCB (identified as Aroclor 1260) ranged from 0.02 to 0.26 µg/l. PCB's were also found in selected sewage treatment plants along the Milwaukee River at concentrations of Aroclor 1254 from 0.12 to 0.25 µg/l *(7)*.

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In order to determine the degree of contamination in other waters in southeastern Wisconsin, this study of sewage treatment plant effluents was designed. Specific objectives of the study were: (1) to determine the composition and concentration of any PCB's present in the waste waters, (2) to establish concentration fluctuations in the treatment plants and (3) to establish the number of pounds of PCB's leaving the plants each day.

STUDY AREA

Samples were collected at the municipal sewage treatment plants in eleven southeastern Wisconsin cities (Fig. 1). Factors used to select these cities were: size of population (1,500 to 100,000), volume of waste flow (140,000 gallons per day to 13 MGD), type of treatment, number and type of industries present and type of receiving water.

Beaver Dam is a city of 15,000 population with paint, glass, foundry and metal fabricators as its major industries. The domestic and industrial wastes average 250,000 gallons per day, and are treated at the municipal plant by a trickling filter, digesters and chlorine before entering the Beaver Dam River.

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Beloit has a population of 35,000. Its major industries are printing, tool and die, chemical formulators and heavy equipment. The total waste flow to the city treatment plant is 5 MGD treated by activated sludge and chlorine before entering the Rock River.

Burlington is a city of 6,000 people with cement, metal work, abrasives, paint, fiberglass, electrical equipment, and chemicals as the major industrial input to the 1.5 MGD waste flow. The waste is treated by a trickling filter, activated sludge and chlorine before it enters the Illinois-Fox River.

Cedarburg is a highly industralized city of 5,000 people. Its industries include casting, plastics, tool and die, printing and paint. The average flow of waste is one MGD which is treated by a trickling filter and chlorine before entering Cedar Creek.

Fort Atkinson has a population of 8,000 people with the following major industries: tool and die, foundry, printing, electrical equipment and paint. The total flow to the municipal sewage treatment plant is 1.3 MGD which is treated by activated sludge, digestion and chlorine before entering the Rock River.

Grafton is a city of 4,000 population with steel products, welding and cutting, casting, printing, concrete, plastics and electrical equipment as its major industries. The 780,000 gallons per day of waste is treated with activated sludge and chlorine before it is discharged into Cedar Creek.

Lake Geneva, with a population of 5,000 people, has a waste flow of 700,000 gallons per day accumulating from both sanitary and industrial wastes. Industries include plastics, electrical fixtures, rubber products and tool and die. Wastes are treated by a trickling filter and chlorine before entering the White River.

Portage is a city of 8,000 people. Concrete products, plastics, hosiery and reproducing paper are its main industries. The combined sanitary and industrial waste is 700,000 gallons per day. It is treated by a trickling filter and chlorine before it is discharged into the Fox River.

The large industrial city of Racine has a population of 100,000. Wastes from its industries--die and molding, precision stamping, casting, foundry, printing, paint, electrical products, chemical treatment and formulators--combine with sanitary wastes to produce 11 MGD of waste. This waste is treated by activated sludge and chlorine before entering Lake Michigan.

Walworth is a small city of 1,500 people with no large industries. The total waste flow is 140,000 gallons per day and is treated with a trickling filter before being released into Walworth Creek.

METHODS

Sampling

Since many plastics and polyvinyl chloride materials may contain a PCB or related interferring compound plasticizer, all-glass containers were used throughout the study to preclude the possibility of sample contamination from the vessel.

The samples were collected by immersing 2½-liter glass bottles in the waste stream at its entrance to the treatment plant, in the primary settling tank, in the trickling filter effluent, and in the final effluent of the sewage treatment plant. The samples were conveyed to the State Laboratory of Hygiene, Madison, Wisconsin, and extracted within 24 hours.

Extraction

The samples were batch-extracted with hexane in separatory funnels. The samples were not filtered because the samples contained small amounts of solids. Hexane (100 ml) was placed in the funnels and the sample (800 ml) was placed in the funnel. After vigorous agitation for one minute, the sample was passed to another funnel also containing hexane (100 ml) and again agitated for one minute. The water portion was then discarded. This procedure was followed until 2400 ml of the sample had been completely extracted. The extracts were combined and concentrated to ten ml for cleanup.

Cleanup

The hexane extracts of the unfiltered effluents were then "cleaned up" to remove certain materials which might interfere with the analyses of the samples for PCB's. This cleanup was done by means of liquid-solid chromatography of florisil *(1, 2, 3, 6)*.

The florisil column used for the cleanup was a ½-inch OD glass column with a 200-ml vessel on the top. The column was fitted with a fritted glass and Teflon stopcock at the bottom. The column was filled with ½ inch of anhydrous Na_2SO_4 and 39 grams of florisil which had been activated at 105 C. The column was then covered with another ½ inch of anhydrous Na_2SO_4 to prevent deactivation from water in the sample extract *(3)*. The columns were pre-wetted with hexane and the extracts (10 ml) were placed on the column and eluted with hexane ether mixture (200 ml, 94/6 percent) at three to five ml/minute *(5)*. This procedure removed all fats, waxes, oils and pigments, leaving an eluate containing PCB's as well as any pesticides that might have been present in the sample.

In order to separate the PCB's from the pesticides, the eluate was concentrated to two ml and passed through a second florisil column. This cleanup was done by means of florisil in a 9-mm ID glass column with 65 ml of hexane as the eluate *(7)*. This procedure removed all pesticides except for DDE [(1,1-dichloro-2,2-bis(*p*-chlorophenyl) ethylene)] which, if present, remained with the PCB's. The extracts were then concentrated to appropriate volumes for analyses of the samples on the gas-liquid chromatograph.

Analysis

Analyses of the cleaned-up extracts to determine the presence of PCB's were made by means of gas-liquid chromatography (GLC) with an electron-capture detector. This technique for isolating and identifying PCB's was the same as that used by Veith *(7)* and Veith and Lee *(8)*.

Gas chromatographic analyses were conducted on a Barber Coleman 5460 Pestalyzer gas chromatograph equipped with a concentric tube, electron-capture detector (^{90}SR). The columns used were six feet by ¼-inch glass coils packed with OV-101/QF-1 (2:2 percent) and OV-101/DC-200 (2:3 percent) coated on Gas Chrom Q (80/100 mesh). The carrier gas (purified nitrogen) was maintained at a flow rate of 28 ml per minute; and the injector, column and detector temperatures were 210 C, 200 C and 270 C respectively.

Identification

From the charts made by the gas chromatograph, identification of the PCB's was made by comparing chromatograms of standard Aroclors with the chromatograms of the samples to determine which Aroclor the sample most resembled. Once an Aroclor was identified in a sample, determination of the concentration present was made by measuring the height of the most prominent peaks in each of the Aroclor standards and comparing these to the height of the most prominent peaks in the sample. In this study, these peaks (isomer components numbers 4 and 7) lay on either side of the first doublet peak (isomer components numbers 5 and 6) (Fig. 2).

The difficulty of this method of identifying which Aroclor is present occurs when a sample contains a mixture of two or more Aroclors. Each Aroclor formulation contains a group of characteristic isomers. These isomers are separated on a gas chromatographic column according to their physical and chemical characteristics. One of these distinguishing characteristics is the percentage of chlorine: each isomer contains a specific number of chlorine atoms. The higher the number of chlorine atoms, the longer the GLC column retains them. The amount of time the isomers are retained on the column is used as an identification technique.

Mixtures of more than one Aroclor may contain some of the same isomers. Therefore, when a sample containing several Aroclors is analyzed, the concentration of one isomer is higher because the same isomer from both Aroclors is analyzed as one component. Figure 3 shows chromatograms of a series of single Aroclors and a mixture of 3 Aroclors on a total ion monitor detector with respect to temperature. As the percent chlorine increases (from 48 to 68 percent), the retention time increases, making the identification of single mixtures less complex. The chromatogram at the bottom of figure 3 is a mixture of Aroclor 1248, 1254 and 1260 and shows the difficulty in identifying the PCB's in a sample containing more than one Aroclor. The analysis of known mixtures like this is the best method of identifying PCB's present in an unknown sample thought to contain a mixture of several Aroclors.

Confirmation

Because of possible complications caused by the presence of more than one Aroclor and because of the possible interference of DDE, identification of some of the samples was confirmed using mass spectrometry (MS). Confirmation was made on 9 of the peaks from 3 of the samples.

The mass spectrometry data was obtained at the Environmental Protection Agency's Southeast Water Laboratory in Athens, Georgia. Analyses were made on the Hatachi Perkin Elmer RMU-7 double focusing instrument interfaced to a PE-900 gas chromatograph with a Watson-Bieman separator. A constant accelerating voltage of 70 electron volts was used. The mass spectrometer data were manually reduced.

In addition to confirming the accuracy of the identification of Aroclors in some samples, confirmation of the estimates of PCB concentrations present was also made. Three samples of raw sewage and three samples of the final effluent were collected from the treatment plant at Cedarburg on October 6, 1971. Each of the 6 samples was extracted with hexane, cleaned up with florisil and injected into the gas chromatograph. Concentrations reported are the average of two injections. Precision of the estimates was determined by corparing the Aroclor concentration in each of the influent samples with the average concentration found in the three samples. Similar comparisons were made for the three samples from the final effluent.

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RESULTS AND DISCUSSION

Confirmatory Data

Accuracy

Of the 3 samples analyzed on the mass spectrometer, identification of PCB's present was the same as the identification reported by the gas chromatograph. Because the original identifications were confirmed and because all samples were analyzed on the gas chromatograph in the same way, identification of the remaining samples was assumed to be qualitatively correct.

Although the MS could not preclude the possible occurrence of materials other than PCB's in the rest of the samples, the sewage treatment plant at Beaver Dam was the only site where possible interference was noted. On the gas chromatograms from this site, PCB's could be detected but the peaks on the graphs were obscured in such a way that the PCB concentrations present could not be determined. This masking effect may have been caused by the presence of DDE in the sample.

Precision

Recoveries of the samples used to test the precision of the Aroclor 1254 analyses are summarized in Table 1. The analyses of the raw sewage samples varied 7 percent from 1.4 µg/l, while analyses of the final effluent samples varied 10 percent from 1.0 µg/l.

Analytical Results

The samples analyzed in this study indicate that Aroclor 1254 is the most common PCB in the sewage effluents. Table 2 shows that PCB's were detected in all samples, at concentrations varying from <0.05 µg/l at Beaver Dam to 2.8 µg/l at Lake Geneva.[1] The mass transport (average pounds per day) of Aroclor 1254 ranged from less than 0.2×10^{-3} to 142×10^{-3} pounds per day at Beaver Dam and Racine, respectively.

Port Washington is not as highly industralized as Grafton; however, the effluents from both cities contained approximately the same concentrations of PCB's. The concentrations ranged from 0.12 to 0.23 µg/l which, based on this study, is an average for cities with little or no industry.

[1] At Beaver Dam, PCB's could be identified on the gas chromatogram, but the concentration could not be determined. In this study, concentrations could be calculated if 0.05 or more mg/l of PCB's were present in the sample.

Cedarburg is an industrialized municipality whose effluents contained concentrations of Aroclor 1254 in the range of 1.0 µg/l. Because the concentrations of PCB's for this city were so high, the fluctuations in concentration throughout a 24-hour day were determined (Table 3). The concentration of PCB's in raw sewage began to increase at the beginning of the working day (8:00) from 0.54 µg/l to a maximum of 3.1 µg/l at 16:00. This variation in PCB concentrations coming into the sewage plant is probably due to incoming wastes from the city's 5 major industries. Also noted in the 24-hour survey was the fact that wastes were retained in the sewage treatment plant from two to four hours. This conclusion was based on the presence of a pink dye in the raw influent at 20:00 and the presence of the same dye in the treated effluent at 22:00.

Figure 4 illustrates the concentration of PCB's in the influent and effluent for a 24-hour period. The concentration of PCB's in the final effluent appears to begin increasing from 0.33 µg/l at 0:00 (midnight) to a maximum of 0.77 µg/l at 14:00. PCB concentrations in both raw and final waste waters seem to increase and decrease at the same times throughout the day; however, since the PCB concentration in the effluent is approximately 30 percent of that in the influent, it is likely that the treatment plant is removing in excess of 70 percent of the PCB's. Table 4 shows that the sludges contain 1,000 times higher concentrations than do the fluid wastes.

Racine is highly industrialized and has a high flow (11 MGD) in its sewage treatment plant. The PCB concentrations varied from 0.60 µg/l on February 19 to 0.83 µg/l on October 6 which was less than the maximum level of PCB's recorded at the Cedarburg plant. However, due to the higher flow, the mass transport of PCB's from the Racine plant is greater than 0.1 pounds per day compared with approximately 0.02 pounds per day from the Cedarburg treatment plant.

Plants in Burlington, Walworth, Beloit and Fort Atkinson have concentrations above the determinable level (0.05 mg/l) but less than 0.40 µg/l. The mass transport of PCB's from the sewage treatment plants in these four cities is less than 0.01 pounds per day.

Lake Geneva is a highly industrialized city whose treatment plant effluents had PCB concentrations between 2.2 and 2.8 µg/l. These high PCB concentrations indicate that the contamination is possibly from industrial wastes. The daily discharge of 0.02 pounds per day was comparable to that for the Cedarburg plant.

Although industries in the city of Portage are few, they contribute between 32 and 42 µg/l of Aroclor 1248 to the sanitary waste flow. A sample of the digester sludge was analyzed at 10:00 and found to contain 5.25 mg/l. It is of interest to note that the city of Portage has reported problems with the operation of their trickling filter which may be due, in part, to the presence of PCB's and other chemicals. With 32-42 µg/l Aroclor 1248 in the waste, it could be toxic to some of the filter fauna. Organic mercury compounds were also found (by the HS method) on the scum of the trickling filter at concentrations up to 90 mg/l.

Data presented in Table 3 demonstrate that the time of sampling waste effluents is of major importance in mass transport estimates. For example, if the Cedarburg effluent were sampled at 14:00 on April 15, 1971, the estimated transport of PCB's out of the plant would be approximately twice that estimated from a sample taken at 8:00. It should be noted, however, that the PCB concentration in the effluent from the plant varied considerably less than that in the raw wastes entering the plant. Consequently, the mass transport may be considered as order-of-magnitude estimates (i.e., estimates are only accurate within 1,000 percent).

The sources of the PCB's entering the sewage treatment plants have not been explicitly identified in this study or in the literature. It is possible that PCB's could be released through the use of household products such as cleaning compounds and waxes which may contain PCB's. For example, Veith (Dep. Water Chem., Univ. Wis., Madison, Wis., unpublished) found PCB's in several detergents designed for electric dishwashers. In addition to these possible household sources, PCB's may be released from leaking heat-exchanges, cutting oils, lubricants, etc. The Monsanto Company, the sole producer of PCB's in the U.S., restricted the sales of PCB's to capacitors, transformers and heat exchange systems in August, 1970, although until August, 1971, PCB's were still sold for industrial uses for which suitable replacement chemicals were not immediately available. Therefore, the presence of PCB's in waste effluents after April, 1971, suggests that this contaminant is arising from stockpiled PCB's.

In January, 1972, Monsanto Company further restricted the use of PCB's by prohibiting the sale of these chemicals for use in heat-exchangers (G. Fred Lee, Dep. Water Chem., Univ. Wis., Madison, Wis., unpublished). PCB's are now available in the U.S. solely for the manufacture of capacitors and fire-proof transformers. Further studies are needed to determine how effective these self-improved restrictions by Monsanto Company will be in reducing the quantities of PCB's entering the environment.

CONCLUSIONS

Summary

The results of this study indicate that 6 of the 11 sewage plants in the study had effluent concentrations in the range of 0.1 to 0.5 µg/l of a compound whose chromatogram appeared to match the chromatogram of Aroclor 1254. Two sites had effluent concentrations greater than 1.0 µg/l of Aroclor 1254. One city had a maximum concentration of 42 µg/l Aroclor 1248 in the effluent waters and 5.2 mg/l Aroclor 1248 in the digester sludge.

Data from the Cedarburg treatment plant show that the time of collection is important because the concentration can vary greatly. The data show that the minimum concentrations of PCB's in the Cedarburg plant are probably 0.33 to 0.30 µg/l of Aroclor 1254, while maximum concentrations range from 1.5 to 3.1 µg/l. Because of these fluctuations from hour to hour, it is difficult to precisely determine the total amount of PCB's being discharged into receiving waters without hourly sampling of the effluent at a given site.

Of the various samples of waste effluents collected, the estimated mass transport of PCB's varied from $<2.0 \times 10^{-4}$ to 142×10^{-3} pounds per day. At Racine, an equivalent of 41.1 pounds of PCB's per year flow into the near shore waters of Lake Michigan and could ultimately contaminate millions of pounds of organisms in the food chain.

The concentration of PCB's in the influent was approximately ten times the concentration in the effluent. Based on the study at the Cedarburg plant, it appears that the treatment of domestic wastes removes 70 percent or more of the PCB's (Aroclor 1254) present in incoming wastes. The fact that most of the PCB's are removed by treatment is also evident in the comparatively high concentration of PCB's found in the digester and primary settling sludges.

Recommendations

Future research on PCB's is needed in the areas of toxicities, degradation and transport. This will enable evaluation of the significance of the observed PCB concentrations in the environment.

Because PCB's were present in all sewage treatment plants studied, more research is needed to locate sources. The relative contributions of industrial and sanitary sources could be estimated by systematically sampling industrial and residential sewers.

A monitoring program on PCB's should be continued to see if the concentrations in domestic waste waters decrease to any significant extent as a result of Monsento's restriction on the sale of the compounds. In addition, further studies should be designed to estimate the significance of hourly fluctuations in PCB concentrations in the interpretation of the resulting data.

ACKNOWLEDGMENT

Grateful acknowledgment is extended to Dr. G. D. Veith for his supervision throughout the study, to Drs. G. Fred Lee and D. E. Armstrong for their reviewing of this thesis, to Jackie Zoch for her aid in the analyses, to Joe Ball for his assistance in sample collection and to Dr. Wayne Garrison and his staff from the Southeast Water Laboratory in Athens, Georgia for their help on mass spectral analyses.

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FIGURE CAPTIONS

FIGURE 1.--Location of sampling sites in southeastern Wisconsin.

FIGURE 2.--Retention time of Aroclor 1254.

FIGURE 3.--Relative retention times of Aroclors 1248, 1254, 1260, 1262 and 1268 *(4)*.

FIGURE 4.---Hourly concentrations of PCB's in the influent and effluent from the Cedarburg treatment plant, April 15, 1971.

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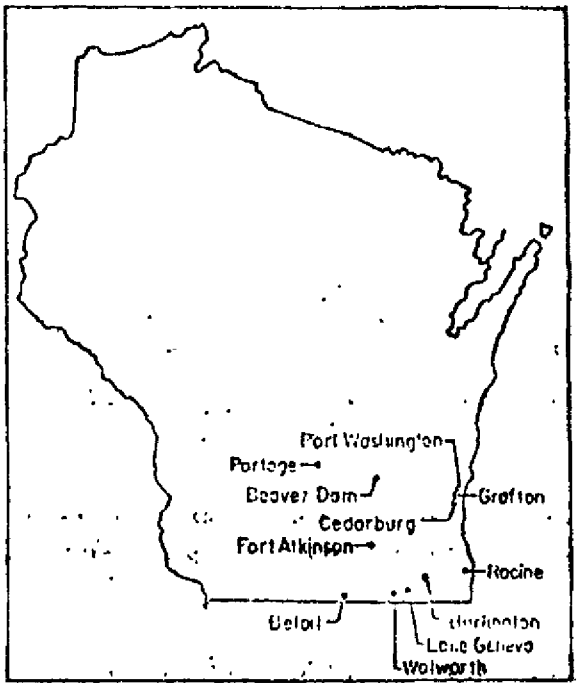
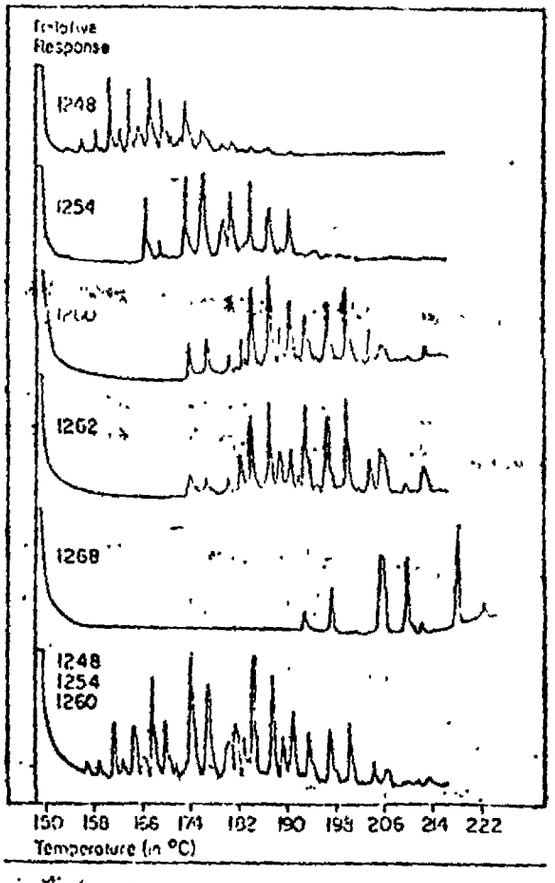
FIGURE 1



MONS 204046

FIGURE 5



MONS 204047

FIGURE 4

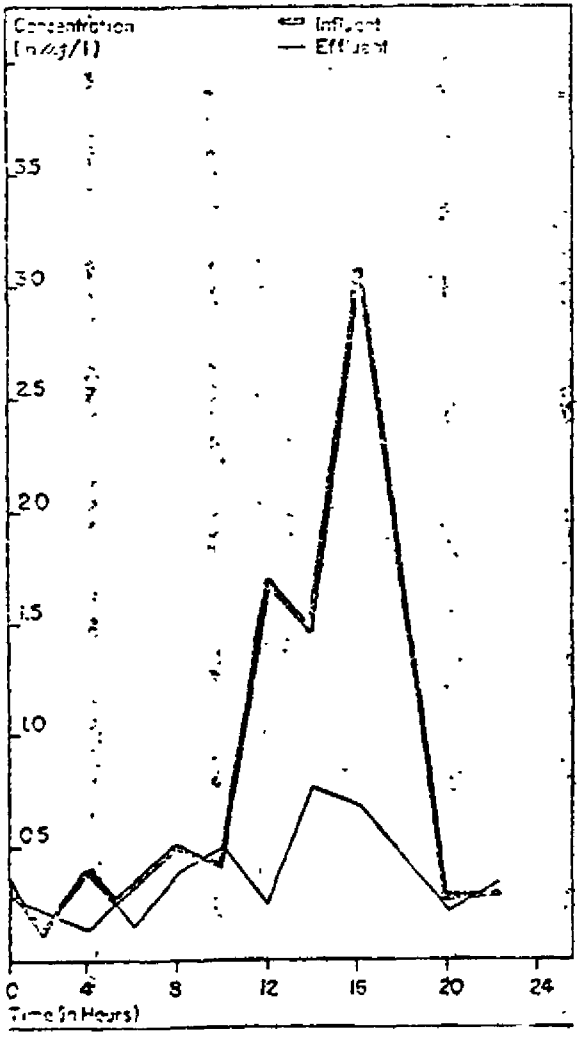


FIGURE 2

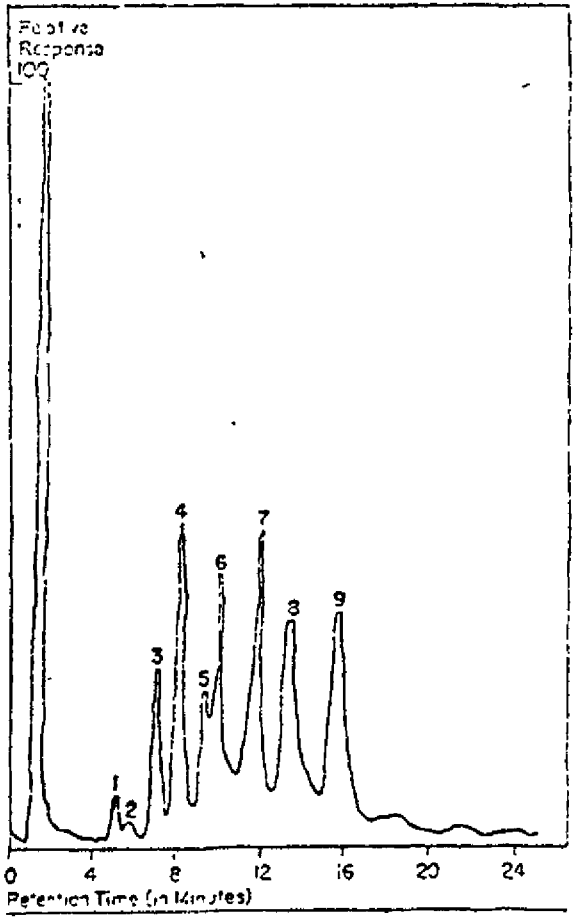


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TABLE 1.--Recovery of PCB's from triplicate samples taken at the Cedarburg treatment plant, October 6, 1971, at 11:30

SAMPLE TYPE & NO.	VOLUME EXTRACTED (in ml)	PCB CONCENTRATION (in $\mu g/l$)[1]
RAW SEWAGE		
Sample 1	3,000	1.5
Sample 2	3,000	1.4
Sample 3	3,000	1.4
FINAL EFFLUENT		
Sample 1	2,500	0.9
Sample 2	2,400	1.1
Sample 3	2,400	1.0

[1] The chromatograms of all samples collected most closely resembled the chromatogram of Aroclor 1254.

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TABLE 2.--PCB concentrations in the effluents from 11 southeastern Wisconsin sewage treatment plants, 1971

CITY	SAMPLING DATE	SAMPLING TIME	PCB CONCENTRATIONS (in µg/l)[1]	WASTE VOLUME FLOW (in MGD)	WASTE VOLUME ESTIMATED MASS TRANSPORT[2] (in lbs PCB's/day at 10^{-3})
Beaver Dam	1/20	6:30	<0.05	1.59	<0.2
	2/19	6:30	<0.05	4.33	-
	3/22	6:30	<0.05	3.50	-
	10/6	6:30	<0.05	2.34	-
Port Washington	1/20	8:30	0.14	0.70	-
	2/19	8:30	0.12	1.27	-
	3/22	8:30	0.22	1.46	2.7
	10/6	8:30	0.19	1.80	-
Grafton	1/9	9:30	0.12	0.84	0.8
	2/19	9:30	0.13	1.00	1.1
	3/22	9:30	0.23	0.78	1.5
	10/6	9:30	0.07	0.84	-
Cedarburg	1/20	10:30	0.48	1.05	4.2
	2/19	10:30	0.28	1.17	2.7
	3/22	10:30	0.97	2.57	-
	10/6	10:30	0.91	1.95	15
	10/6	10:30	1.1	1.95	18
	10/6	10:30	1.0	1.95	16

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TABLE 2.--PCB concentrations in the effluents from

11 southeastern Wisconsin sewage treatment plants, 1971 (cont.)

CITY	SAMPLING DATE	SAMPLING TIME	PCB CONCENTRATIONS (in µg/l)[1]	WASTE VOLUME FLOW (in MGD)	WASTE VOLUME ESTIMATED MASS TRANSPORT[2] (in lbs PCB's/day at 10^{-3})
Racine	1/20	8:30	0.72	16.45	-
	2/19	12:00	0.60	25.06	-
	3/22	12:00	0.76	23.01	-
	10/6	12:00	0.83	20.51	142
Burlington	1/20	9:30	0.14	1.74	-
	2/19	13.00	0.09	2.61	-
	3/22	13:00	0.08	2.50	1.7
	10/6	13:00	0.12	1.35	-
Lake Geneva	1/20	10.30	2.5	0.56	-
	2/19	14:00	2.2	0.66	-
	3/22	14:00	2.8	0.78	18
	10/6	14:00	2.4	0.54	-
Walworth	1/19	11:00	0.17	-	-
	2/20	14:30	0.21	-	-
	3/22	14:30	0.34	-	-
	10/6	14:30	0.18	-	-

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TABLE 2.--PCB concentrations in the effluents from 11 southeastern Wisconsin sewage treatment plants, 1971 (cont.)

CITY	SAMPLING DATE	SAMPLING TIME	PCB CONCENTRATIONS (in µg/l)[1]	WASTE VOLUME FLOW (in MGD)	WASTE VOLUME ESTIMATED MASS TRANSPORT[2] (in lbs PCB's/day at 10^{-3})
Beloit	1/19	12:30	0.11	3.89	-
	2/20	16:00	0.07	11.75	-
	3/22	16:00	0.06	7.56	3.8
	10/6	16:00	0.14	4.42	5.2
Fort Atkinson	1/19	2:00	0.15	1.24	-
	2/20	16:00	0.07	2.48	-
	3/2[illegible]	18:00	0.10	1.85	1.5
	10/6	16:00	0.08	1.30	-
Portage	5/20	10:00	42	0.79	-
	9/20	10:00	38	1.00	-
	10/6	10:00	32	0.78	-

[1] The chromatograms from all cities except for Portage most closely resembled the chromatogram of Aroclor 1254; the chromatogram from the Portage samples most closely resembled the chromatogram of Aroclor 1248.

[2] Mass transport estimates were made by dividing the number of pounds of PCB's discharged by the plant per day by the average flow of wastes into the plant per day.

TABLE 3.--A 24-hour survey of PCB's

in the Cedarburg treatment plant on April 15, 1971

TIME	FLOW (in gal/min)	PCB CONCENTRATIONS (in μg/l)[1]		
		IN THE INFLUENT	IN THE EFFLUENT	IN THE PRIMARY TRICKLING FILTER
0:00	1480	0.30	0.33	-
1:00	1360	-	-	0.19
2:00	1300	0.20	0.10	-
4:00	1250	0.13	0.35	-
6:00	1200	-	0.16	-
8:00	2000	0.54	0.39	-
10:00	2100	0.40	0.50	-
12:00	1900	1.7	0.23	0.69
14:00	1900	1.5	0.77	-
16:00	1850	3.1	0.70	-
17:00	1900	-	-	0.25
20:00	1950	0.30	0.22	-
21:00	1800	-	-	0.14
22:00	1650	0.36	0.34	-

[1] The chromatograms of the samples most closely resembled the chromatogram of Aroclor 1254.

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TABLE 4.--PCB concentrations in the Cedarburg treatment plant, April 15, 1971

TIME	PCB CONCENTRATIONS (in mg/l)[1]	
	DIGESTER SLUDGE	PRIMARY SETTLING SLUDGE
10:00	24	69
16:00	20	31

[1] The chromatograms of the samples most closely resembled the chromatogram of Aroclor 1254.

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EFFECT OF DIETARY POLYCHLORINATED BIPHENYLS ON GROWTH AND REPRODUCTION OF MINK

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The Great Lakes have played a prominent role in the development of the mink industry in nearby states as these lakes furnished the rancher with an inexpensive and abundant supply of fish deemed desirable for mink feed. During the middle 1960s, reports from mink ranchers stating that reduced reproduction was a consequence of feeding Great Lakes fish were called to the attention of university researchers (Hartsough, 1965). Coho salmon taken from the tributaries of Lake Michigan during the spawning run in 1967 were made available to commercial ranchers as food for mink and resulted in a precipitous increase in newborn mink (kit) mortality. The extent of mortality appeared as a time-dosage response to coho salmon in the diet. Adult breeders were reported to be unaffected. Rancidity, chlorinated hydrocarbon pesticide contamination and mercury poisoning were each prominent suspects as the causative agent responsible for the high kit mortality. Because of the disastrous effect of feeding coho salmon, mink ranchers discontinued use of Great Lakes fish in mink diets.

In 1969 our laboratory confirmed the mink industry's observation that Lake Michigan coho salmon, when fed to breeder mink, resulted in either total cessation of mink reproduction (embryo toxicity) or kit mortality, the degree of complication being dependent upon the percentage coho salmon fed and the duration of feeding (Aulerich et al., 1971). Coho salmon per se were not implicated since west coast coho salmon yielded totally acceptable reproductive parameters. Subsequent reproduction studies yielded data indicating that the causative agent(s) was not confined solely to the salmon from Lake Michigan, but was apparently present, although to a lesser extent, in other fish from the Great Lakes (Aulerich et al., 1971).

Lake diet and mercury contamination data for the various fish did not correlate with mink toxicity data and each was discounted as a contributor to the problem, however, hydrocarbon pesticide contamination (total DDT and isomers or dieldrin) of the fish fed was inversely proportional to number of mink offspring born per female. The relationship appears spurious and may reflect, in part, the fat content of the fish. Feeding either DDT and isomers or dieldrin in levels far in excess of that found analytically in the fish failed to simulate the effect on mink of feeding diets containing coho salmon (Aulerich and Ringer, 1970; Aulerich et al., 1971).

This study was undertaken to investigate the effects of polychlorinated biphenyls, known to contaminate Lake Michigan and its fish, on growth and reproduction of ranch mink.

Preprints of Papers Presented at 164th Nat'l. Meeting
American Chemical Society, Vol. 12 (2):149-154, 1972

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MATERIALS AND METHODS

This study consisted of three feeding trials encompassing polychlorinated biphenyls (PCB) supplementation to mink. PCB supplementation was by incorporating the Aroclor[2] into a cereal grain premix and then into the diet. The raw basal (control) diet, except as specified, was fed in all experiments. The diet composition was cereal, 15%; tripe, 20%, beef liver, 5%, horsemeat, 15%, chicken, 15%; and fish, 30%. Standard ranch procedures of animal care and breeding were used throughout the course of the experiments.

RESULTS

Experiment 1

A total of 65 mink were divided into 3 groups (12 females and 3 males per dietary treatment group). The treatments were a basal diet containing ocean fish, substitution of coho salmon for the ocean fish, and the basal diet supplemented with 10 ppm each of Aroclors 1242, 1248, and 1254.

No female mink receiving dietary coho salmon bore young (whelped) nor did those receiving 30 ppm PCB supplementation (Table 1). All adult mink fed supplemental PCB's died by the end of the normal whelping period. Those females on PCB's that survived sufficient time to produce offspring showed no signs of whelping. Six mink fed coho salmon died during the experimental period of January 1 to June 30. No adult control mink died.

Table 1

Effect of Dietary PCB Supplementation[1] on Reproduction of Ranch Mink (January 1 to June 30)

	Females mated	Females whelped	Kits born Alive	Kits born Dead	Kits alive (4 wks)
Basal (control)	12	11	35	19	29
30% coho salmon	12	0	0	0	0
Basal + 30 ppm PCB's	11[2]	0	0	0	0

(1) 10 ppm each of Aroclors 1242, 1248, and 1254.
(2) One female died prior to the mating season.

Tissue analysis for PCB residues from several mink that died while on experimentation are shown in Table 2. Control mink were sacrificed for tissue analysis. The similarity in the tissue residues of the PCB

Aroclor® is the trade name of polychlorinated biphenyls by Monsanto Company, St. Louis, Mo.

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treatment and the coho treatment group at stripping. Organ weights expressed as a percentage of brain weight from those mink that died and from sacrificed controls were not significantly different ($P > 0.05$).

Table 2

PCB Tissue Residues (in ppm) of Mink that Died While Receiving Dietary Coho Salmon or Supplemental PCB's[1] and from Sacrificed Controls (Mean ± S.E.)

	Basal (control)	30% coho salmon	Basal + 30 ppm PCB's
No. mink	4	3	12
Brain	< 0.01	11.07 ± 0.78	11.00 ± 1.43
Liver	< 0.01	5.21 ± 1.66	4.18 ± 0.58
Kidney	< 0.01	6.37 ± 0.25	4.47 ± 0.42
Spleen	< 0.01	6.19 ± 0.09	4.79 ± 0.39
Lung	< 0.01	5.15 ± 0.22	4.78 ± 0.53
Muscle	< 0.01	4.73 ± 1.80	4.88 ± 0.54
Heart	< 0.01	2.84 ± 1.21	3.26 ± 0.49

(1) 10 ppm each of Aroclors 1242, 1248, and 1254.

Experiment II

Thirty five mink were divided into five groups of six females and one male per group. Dietary treatments were initiated on August 25 to measure growth rate of young, growing mink and will continue until June 30 when the reproductive phase is complete. Treatments consisted of a basal diet with ocean fish, basal plus 5 ppm Aroclor 1254, basal plus 10 ppm Aroclor 1254, basal plus 10 ppm Aroclor 1254 and 10 ppm DDT, and basal plus 10 ppm Aroclor 1254 and 0.5 ppm dieldrin.

Results of body weight gains for the growth phase from August 25 to December 22 are shown in Table 3. Results for the reproduction phase are included in Table 4.

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Table 3

Effect of Aroclor 1254, Alone or in Combination with Pesticides, on Body Weight Gain of Female Mink

Dietary treatment	No. Mink	Initial body wt. (gm) (Aug. 25)	Body weight gain (gm) ± S.E. from initial wt. 1 mo (Sept. 26)	2 mo. (Oct. 25)	3 mo. (Nov. 25)	4 mo. (Dec. 22)
Basal diet (30% ocean fish mix, control)	6	1020	43 ± 17.4	203 ± 25.4	187 ± 46.2	210 ± 35.1
Basal diet plus 5 ppm PCB[1]	6	940	62 ± 22.4	153 ± 44.2	138 ± 42.7	128 ± 43.7
Basal diet plus 10 ppm PCB	6	923	43 ± 20.4	148 ± 32.0	137 ± 26.3	92 ± 35.1*
Basal diet plus 10 ppm PCB and 10 ppm DDT	6	1052	43 ± 14.5	57 ± 14.6**	28 ± 21.5**	-15 ± 35.4**
Basal diet plus 10 ppm PCB and 0.5 ppm dieldrin	6	940	108 ± 25.1	233 ± 26.7	115 ± 18.9	57 ± 24.4**

(1) Aroclor 1254.
*Significantly different ($P < 0.05$) from controls.
**Significantly different ($P < 0.01$) from controls.

Table 4

Effect of Aroclor 1254, Fed Alone or in Combination with Pesticides, on Mortality and Reproduction of Mink (Aug. 25 to May 10)
(6 females and 1 male/group)

	% mortality	Females alive	Females whelped	Alive	Dead	Kits alive
Control	14	5	3	17	8	5.0
5 ppm PCB[1]	29	4	0	0	0	0
10 ppm PCB	71	1	0	0	0	0
10 ppm PCB + 10 ppm DDT	43	4	0	0	0	0
10 ppm PCB + 0.5 ppm dieldrin	100	0	0	0	0	0

(1) Aroclor 1254

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Data from this experiment demonstrate that 10 ppm Aroclor 1254 depressed growth rates, when fed continuously to growing mink. A dose-response curve for data on 0, 5, and 10 ppm Aroclor 1254 at 4 months treatment yielded a regression equation of $\hat{Y} = 207.5 - 107.4X$ where $X = \ln(\frac{ppm}{5} + 1)$. This regression equation gives a significant dose-response ($P < .05$).

All mink fed PCB supplemented diets failed to produce offspring. Those breeders that died during the gestation period exhibited various degrees of embryo toxicity when the uterus was opened for examination.

Experiment III

One hundred twenty-eight mink were divided into eight groups of twelve females and four males per group to evaluate the effect of Aroclor 1254 on reproduction. The dietary treatments were initiated on January 1 and will continue until June 30. Included in the treatments (Table 5) was a group given 5 ppm Aroclor 1254 plus 6 ppm DDT and 0.2 ppm dieldrin. These levels approximate the residue values found in diets where 30 percent raw Lake Michigan coho salmon constituted the fish portion of the diet. Cooked coho salmon (120° C at 1.05 kg/sq cm for 30 min) was included to test for the heat stability of the factor(s) causing the reproductive problem.

Table 5

Effect of Aroclor 1254 fed Singly and in Combination with Hydrocarbon on Reproductive Parameters (Jan 1 to May 10) (12 females and 4 males/group)

	% mortality	Females alive	Females whelped	Kits Born Alive	Kits Born Dead	Kits/female alive
Control (no ran fish)	0	11	11	56	10	6.0
Raw coho salmon	19	11	0	0	0	0
Cooked coho salmon	6	12	0	0	0	0
1 ppm PCB[1]	6*	10	8	35	8	4.3
5 ppm PCB	0	12	3	3	6	0.8
15 ppm PCB	31	8	0	0	0	0
5 ppm PCB + 6 ppm DDT	0	12	4	5	6	0.9
5 ppm PCB + 6 ppm DDT + 0.2 ppm dieldrin	19	10	5	15	3	2.2

(1) Aroclor 1254.
* One female escaped.

Data in table 5 indicate that 5 ppm Aroclor 1254 markedly reduced reproduction when fed only 4 months, 1 ppm Aroclor 1254 caused only slight reduction and 15 ppm PCB totally inhibited reproduction. The factor(s) present in Lake Michigan coho salmon was heat stable and duplication, in

part, of several factors known to be present in the salmon did not totally reproduce the coho salmon effect.

The results of these experiments clearly point out the sensitivity of mink to polychlorinated biphenyls and cast suspicion on PCB's as a possible factor involved in the poor reproduction following Lake Michigan coho salmon feeding.

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PCBs and DDT in Fish From Western Lake Superior

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PCBs and DDT in Fish

From Western Lake Superior

Fish from western Lake Superior were collected as available with gill nets by the Wisconsin Department of Natural Resources (Apostle Island region) and the National Water Quality Laboratory (Little Two Harbors and Illgen City regions) during 1972 and 1973. The fish were frozen, homogenized, and analyzed for PCBs and DDT analogues. The presence of PCBs was confirmed by perchlorinating the PCBs to decachlorobiphenyl with $SbCl_5$.

Table 1 presents mean and standard deviations for the major chlorinated hydrocarbons in burbot, lake trout, chubs, herring, and smelt from the three sampling regions. The mean concentration (whole fish) of PCBs (most resembling Aroclor® 1254) ranged from 0.3 µg/gm in smelt to 1.8 µg/gm in lake trout. The maximum concentration of PCBs was 5.6 µg/gm in a large lake trout captured in the Apostle Island region.

MONS 204062

Table 1. Concentration of Major Chlorinated Hydrocarbons in Fish from Western Lake Superior.

Species	Number of Fish	Mean Weight[a] (gm)	Mean Lipid (percent)	Dieldrin (ug/gm)	p,p' DDE (ug/gm)	Total DDT Analogues[b] (ug/gm)	PCBs (ug/gm) Aroclor 1254
APOSTLE ISLAND REGION (Wisconsin) November, 1973							
Burbot	3	1290±200 (1057-1474)	6.2±1.4 (4.8-7.7)	0.03 (0.03)	0.7±0.3 (0.4-0.9)	0.4±0.2 (0.2-0.6)	1.4±0.4 (1.0-1.7)
Lake Trout	9	2600±1700 (257-5652)	8.9±3.6 (1.4-13.0)	0.03±0.02 (<0.03-0.05)	2.2±2.3 (0.05-6.9)	3.7±4.2 (0.1-12.8)	1.8±1.6 (0.3-5.6)
Long-Nose Sucker	8	970±160 (569-1073)	6.1±3.7 (1.9-12)	0.03±0.03 (<0.03-0.09)	0.8±0.9 (0.16-2.60)	1.5±1.6 (0.3-3.3)	0.9±0.8 (0.3-2.7)
Smelt	5	64±6 (57-72)	8.2±2.2 (6.7-12)	<0.03	0.17±0.04 (0.11-0.20)	0.28±0.06 (0.18-0.33)	0.4±0.1 (0.4-0.5)
LITTLE TWO HARBORS REGION (Minnesota) July, 1972							
Burbot	4	410±80 (320-502)	3.3±0.8 (2.3-4.2)	<0.03	0.2±0.2 (0.05-0.46)	0.4±0.3 (0.08-0.77)	0.5±0.5 (<0.9-1.0)
Chubs	14	172±75 (77-390)	11.1±8.2 (1.2-26.0)	<0.03	0.8±0.4 (0.08-1.65)	1.3±0.7 (0.69-3.01)	1.0±0.3 (0.40-1.60)
Herring	3	305±70 (231-370)	5.3±3.0 (1.9-7.8)	<0.03	0.6±0.2 (0.44-0.86)	1.3±0.6 (0.89-1.93)	2.0±1.0 (1.2-3.1)
Lake Trout	12	400±100 (202-552)	6.1±2.8 (2.6-13.0)	<0.03	0.5±0.2 (0.11-0.84)	0.9±0.4 (0.21-1.45)	0.8±0.4 (<0.3-1.5)
Smelt	8	40±10 (27-52)	2.1±2.9 (0.6-6.5)	<0.03	0.2±0.1 (0.06-0.41)	0.3±0.2 (0.10-0.68)	0.4±0.5 (<0.4-1.2)

MONS 204063

Table 1 con't.

Species	Number of Fish	Mean Weight[a] (gm)	Mean Lipid (percent)	Dieldrin (ug/gm)	pp' DDE (ug/gm)	Total DDT Analogues[b] (ug/gm)	PCBs (ug/gm) Aroclor 1254
ILLGEN CITY REGION (Minnesota) July, 1972							
Burbot	6	430±300 (158-1006)	7.1±2.4 (4.0-10.2)	<0.03	0.5±0.2 (0.31-0.74)	0.8±0.3 (0.54-1.28)	0.9±0.3 (0.5-1.2)
Chubs	6	320±90 (245-484)	9.1±3.4 (5.2-12.8)	<0.03	0.5±0.2 (0.35-0.76)	1.3±0.4 (0.85-1.92)	0.7±0.2 (0.4-0.9)
Lake Trout	10	390±210 (106-733)	4.6±1.1 (2.8-6.9)	<0.03	0.6±0.4 (0.20-1.40)	0.9±0.5 (0.28-1.68)	0.7±0.3 (0.3-1.2)
Smelt	10	45±10 (39-66)	2.8±1.2 (1.4-4.6)	<0.03	0.2±0.1 (0.12-0.30)	0.3±0.1 (0.21-0.49)	0.3±0.1 (0.2-0.5)

[a] Data expressed at mean ± S. D.; the range is presented in parenthesis.

[b] Total DDT = Σ(pp' DDE + op' DDT + pp' DDD + pp' DDT).

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MAY 28 1974

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1973
GREAT LAKES ENVIRONMENTAL
CONTAMINANT SURVEY

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DATA, SUMMARY AND ANALYSIS
by
Michigan Department of Agriculture
Bureau of Consumer Protection

MONS 204065

GREAT LAKES ENVIRONMENTAL

CONTAMINANT SURVEY

1973

Data from the 1973 Great Lakes Environmental Contaminant Survey (GLECS) conducted by the Michigan Department of Agriculture, the Michigan Department of Natural Resources, the U. S. Food and Drug Administration--Detroit Region, and the USDI Bureau of Sport Fisheries and Wildlife--Ann Arbor Laboratory are presented in total in this report. A summary prepared by the Michigan Department of Agriculture is also presented.

Fish were collected by DNR field personnel and analyzed in the laboratories of the other three participating agencies. Tissue sampling and analytical procedures were comparable in all cases. Procedural details are available on request to participants.

A similar program of sampling, analysis, and reporting is planned for the 1974 season. Each participating agency also conducts sampling and analysis for special purposes not included in this study.

MONS 204066

GREAT LAKES ENVIRONMENTAL CONTAMINANT 1973 SURVEY

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NONS 204067

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

BROWN TROUT

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE HURON						
MH-2	<21"	3	1.3	2.0	.19	.05
(Thunder Bay)	>21"	3	3.1	5.2	.28	.08

MONS 204068

ID	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB's	MERCURY
T0193	Br.Trout	MH-2(Th.Bay)	9-20-73	19.7	4.2	MDA	22701	1.60	0.07	2.58	0.19
T0194	Br.Trout	MH-2(Th.Bay)	9-20-73	19.3	3.6	MDA	22701	1.00	0.02	1.37	0.20
T0195	Br.Trout	MH-2(Th.Bay)	9-20-73	20.8	4.6	MDA	22701	1.36	0.05	2.06	0.18
T0196	Br.Trout	MH-2(Th.Bay)	9-20-73	26.4	9.2	MDA	22701	3.78	0.07	6.89	0.25
T0197	Br.Trout	MH-2(Th.Bay)	9-20-73	28.9	14.3	MDA	22701	3.02	0.08	5.17	0.24
T0198	Br.Trout	MH-2(Th.Bay)	9-20-73	28.4	13.2	MDA	22701	2.48	0.08	3.44	0.35

MONS 204069

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

CARP

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE ERIE						
SWAN CREEK	18-25"	6	1.3± .7	9.3±4.9	.34±.19	.02

MONS 204070

ID. NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3E022	Carp	Swan Creek	5-9-73	18.4	4.00	FDA	040-985G	1.07	Trace	6.7	0.44
3E023	Carp	Swan Creek	5-9-73	19.7	3.75	FDA	040-986G	0.84	Trace	7.2	0.65
3E024	Carp	Swan Creek	5-9-73	18.9	2.90	FDA	040-987G	0.21	0.02	1.9	0.07
3E025	Carp	Swan Creek	5-9-73	21.1	5.20	FDA	040-988G	1.89	0.03	11.9	0.33
3E026	Carp	Swan Creek	5-9-73	24.9	8.50	FDA	040-989G	2 01	0.03	14.5	0.26
3L027	Carp	Swan Creek	5-9-73	23.2	6.25	FDA	040-990G	1 96	0.01	13.7	0.28

MONS 204071

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

CATFISH

Zone	Size	Number	Total DDT's ppm	Total PCB's ppm	Hg ppm	Dieldrin ppm
LAKE HURON (Saginaw Bay)						
CONSUMER POWER	15-18"	4	.5	4.1	.42	.02
DETROIT EDISON	19-20"	2	1.1	7.1	.26	.03
STATION 4	15-18"	4	.6	2.3	.42	.02
	18-23"	5	1.5± .6	3.5±1.6	.60±.12	.04
MH-4	13-16"	3	.4	2.2	.06	.01
	21-23"	4	3.6	11.0	.25	.05
					(.26 chlordane)	

FDA No.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
C-41697	Catfish	MH-4(1608)	6-29-73	25	5 lb. 3 oz.	MDA	12336	6.30	0.07	14.28	0.35
C-41696	Catfish	MH-4(1608)	6-29-73	25	6 lb. 2 oz.	MDA	12335	6.80	0.13	12.85	0.38
C-41695	Catfish	MH-4(1608)	6-29-73	21 3/4	3 lb.11 oz.	MDA	12334	4.97	0.13	8.92	0.30
C-41694	Catfish	MH-4(1608)	6-29-73	21	3 lb. --	MDA	12333	5.49	0.11	11.42	0.28
C-41693	Catfish	MH-4(1608)	6-28-73	21	3 lb. 1 oz.	MDA	12332	4.95	0.09	10.35	0.26
C-41692	Catfish	MH-4(1608)	6-28-73	21½	3 lb. --	MDA	12331	4.84	0.09	9.28	0.28
C-41691	Catfish	MH-4(1608)	6-28-73	21	3 lb. 7 oz.	MDA	12330	4.38	0.11	8.57	0.36
C-41690	Catfish	MH-4(1608)	6-28-73	19	2 lb. 2 oz.	MDA	12329	5.47	0.09	12.91	0.33
C-41689	Catfish	MH-4(1608)	6-28-73	19	2 lb. 1 oz.	MDA	12328	3.44	0.04	7.49	0.25
C-41688	Catfish	MH-4(1608)	6-28-73	18	1 lb.12 oz.	MDA	12327	3.66	0.07	7.49	0.23
C-41683	Catfish	MH-4(Heisterman Is.)	6-28-73	22½	4 lb. 6 oz.	MDA	12322	4.38	0.07	7.69	0.29
C-41682	Catfish	MH-4 (")	6-28-73	23 3/4	5 lb. 5 oz.	MDA	12321	4.98	0.11	8.84	0.39
C-41681	Catfish	MH-4 (")	6-28-73	24	5 lb. 4 oz.	MDA	12320	4.64	0.07	9.23	0.31
C-41680	Catfish	MH-4 (")	6-28-73	23	5 lb. 1 oz.	MDA	12319	4.44	0.10	8.07	0.35
C-40422	Catfish	MH-4 (")	6-21-73	18	2 lb. 4 oz.	MDA	12311	4.09	0.12	8.00	0.22
C-40424	Catfish	MH-4 (")	6-21-73	19½	2 lb.15 oz.	MDA	12313	3.81	0.13	6.60	0.29
C-40425	Catfish	MH-4 (")	6-21-73	18½	2 lb. 2 oz.	MDA	12314	4.72	0.13	10.80	0.23
C-41676	Catfish	MH-4 (")	6-21-73	19 3/4	2 lb.12 oz.	MDA	12315	4.64	0.13	8.40	0.34
C-41677	Catfish	MH-4 (")	6-21-73	20	2 lb.14 oz.	MDA	12316	4.29	0.09	8.80	0.20
C-41678	Catfish	MH-4 (")	6-21-73	20 3/4	3 lb. 9 oz.	MDA	12317	4.77	0.14	9.60	0.23
C-41679	Catfish	MH-4 (")	6-21-73	21½	3 lb.12 oz.	MDA	12318	6.40	0.09	13.07	0.28
C-40423	Catfish	MH-4 (")	6-13-73	18	2 lb. 5 oz.	MDA	12312	2.67	0.10	4.80	0.22
3E253	Catfish	MH-4(Sag.)	10-3-73	22.9	4.56	FDA	042-882G	3.78	0.06	10.6	0.27 0.2
3E254	Catfish	MH-4(Sag.)	10-3-73	21.3	3.42	FDA	042-883G	3.10	0.05	9.1	0.23 0.2
3E255	Catfish	MH-4(Sag.)	10-3-73	21.0	3.42	FDA	042-884G	3.14	0.06	7.5	0.25 0.2
3E258	Catfish	MH-4(Sag.)	10-23-73	22.7	4.05	FDA	042-885G	4.53	0.02	16.6	0.25 0.2

*Chlordane

MONS 204073

FDA No.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
C-41687	Catfish	MH-4(1608)	6-28-73	17½	1 lb. 12 oz.	MDA	12326	3.98	0.06	9.99	0.34
C-41686	Catfish	MH-4(1608)	6-18-73	17½	1 lb. 12 oz.	MDA	12325	2.79	0.05	4.99	0.23
C-41685	Catfish	MH-4(1608)	6-18-73	16½	1 lb. 4 oz.	MDA	12324	2.32	0.05	4.61	0.23
C-41684	Catfish	MH-4(1608)	6-18-73	16	1 lb. 3 oz.	MDA	12323	2.74	0.05	4.99	0.22
C-40421	Catfish	MH-4(Heist-erman Is.)	6-21-73	17	1 lb. 12 oz.	MDA	12310	3.47	0.10	6.80	0.11
C-40418	Catfish	MH-4(")	6-13 73	16½	1 lb. 8 oz.	MDA	12307	1.88	0.05	4.40	0.21
C-40419	Catfish	MH-4(")	6-13-73	16½	1 lb. 8 oz.	MDA	12308	2.20	0.06	4.40	0.19
C-40420	Catfish	MH-4(")	6-13-73	16 3/4	1 lb. 10 oz.	MDA	12309	1.95	0.06	3.60	0.14
3E250	Catfish	MH-4(Sag.)	10-3-73	14.3	0.88	FDA	040-999G	0.25	0.01	1.5	0.01
3E251	Catfish	MH-4(Sag.)	10-3-73	15.9	1.16	FDA	041-000G	0.79	0.01	3.3	0.09
3E252	Catfish	MH-4(Sag.)	10-3-73	13.1	0.70	FDA	042-881G	0.22	Trace	1.8	0.08

MONS 204074

DA C.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
FO335	Catfish	Cons. Power	9-9-73	15.3	1.48	FDA	040-993G	0.60	0.03	4.3	0.37
FO336	Catfish	Cons. Power	9-9-73	14.7	1.16	FDA	040-994G	0.52	0.02	3.6	0.25
FO337	Catfish	Cons. Power	9-9-73	16.4	1.60	FDA	040-995G	1.03	0.02	5.9	0.53
FO338	Catfish	Cons. Power	9-9-73	18.0	2.08	FDA	040-996G	0.32	0.02	2.5	0.52
FO339	Catfish	Det.Edison	9-12-73	19.4	2.58	FDA	040-997G	0.78	0.04	5.2	0.24
FO340	Catfish	Det.Edison	9-12-73	19.3	2.37	FDA	040-998G	1.51	0.03	9.0	0.29

MONS 204075

NJA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3C007	Catfish	Sta. 4	5-30-73	15.5	1.19	FDA	108-207G	0.21	Trace	1.5	0.40
3C008	Catfish	Sta. 4	5-30-73	16.1	1.20	FDA	108-208G	0.64	0.03	1.8	0.31
3C009	Catfish	Sta. 4	5-30-73	13.5	0.68	FDA	108-209G	0.29	Trace	1.4	0.42
3C010	Catfish	Sta. 4	5-30-73	17.8	2.30	FDA	108-210G	1.28	0.06	4.3	0.55
3C011	Catfish	Sta. 4	5-30-73	18.6	2.05	FDA	108-211G	0.88	0.02	2.7	0.40
3C012	Catfish	Sta. 4	5-30-73	19.8	2.79	FDA	108-212G	1.93	0.06	3.6	0 66
3C013	Catfish	Sta. 4	5-30-73	20.5	3.18	FDA	108-213G	0.79	0.03	1.2	0.70
3C014	Catfish	Sta. 4	5-30-73	25.6	6.06	FDA	108-214G	2.05	0.05	5.1	0.62
3C015	Catfish	Sta. 4	5-30-73	23.2	4.86	FDA	108-215G	1.96	0.05	5.0	0.62

MONS 204076

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

CHUBS

Zone	Size	Number	Total DDT's ppm	Total PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
MM-6	#1	3	2.5	2.3	.11	.19
	#2	3	2.8	3.0	.13	.17
MM-8	--	6	2.2±1.2	6.3±2.6	.13±.05	.03
LAKE SUPERIOR						
MS-2	--	6	1.4±1.0	1.4±.5	.19±.04	N.D.
MS-3	--	6	2.3±.5	1.7±.7	.20±.09	tr

MONS 204077

DA #	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
F0135	Chubs	MM-6	8-9-73	#1	--	MDA	18769	3.08	0.24	2.55	0.13
F0136	Chubs	MM-6	8-9-73	#1	--	MDA	18769	1.87	0.13	1.78	0.13
F0137	Chubs	MM-6	8-9-73	#1	--	MDA	18769	2.56	0.19	2.67	0.10
F0138	Chubs	MM-6	8-9-73	#2	--	MDA	18770	2.43	0.15	3.12	0.13
F0139	Chubs	MM-6	8-9-73	#2	--	MDA	18770	1.90	0.17	2.69	0.10
F0140	Chubs	MM-6	8-9-73	#2	--	MDA	18770	4.06	0.18	3.07	0.17
	Chubs	MM-8		11.3	0.6	BSFW		3.7	0.05	11.0	0.20
	Chubs	MM-8		12.6	1.0	BSFW		3.9	0.03	7.3	0.18
	Chubs	MM-8		11.1	0.6	BSFW		1.3	0.02	5.2	0.096
	Chubs	MM-8		10.5	0.4	BSFW		1.3	0.02	3.3	0.081
	Chubs	MM-8		10.1	0.4	BSFW		1.7	0.02	6.0	0.12
	Chubs	MM-8		10.2	0.4	BSFW		1.6	0.04	4.9	0.10

MONS 204078

ID NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF468	Chub	MS-2(1414)	7-11-73	13.4	--	BSFW	--	3.1	N.D.	1.9	0.25
SF469	Chub	MS-2(1414)	7-11-73	12.3	--	BSFW	--	0.92	N.D.	1.2	0.16
SF470	Chub	MS-2(1414)	7-11-73	11.6	--	BSFW	--	0.56	N.D.	0.78	0.19
SF471	Chub	MS-2(1414)	7-11-73	10.9	--	BSFW	--	1.0	N.D.	1.2	0.18
SF472	Chub	MS-2(1414)	7-11-73	12.3	--	BSFW	--	2.1	N.D.	2.2	0.23
SF473	Chub	MS-2(1414)	7-11-73	11.2	--	BSFW	--	0.73	N.D.	1.1	0.13
SF197	Chub	MS-3(1127)	5-10-73	9-10-11	--	MDA	17475	2.56	0.02	1.37	0.12
SF197	Chub	MS-3(1127)	5-10-73	10	--	BSFW	--	1.6	N.D.	1.1	0.17
SF198	Chub	MS-3(1127)	5-10-73	13	--	BSFW	--	2.3	N.D.	2.3	0.26
SF198	Chub	MS-3(1127)	5-10-73	12-13-14	--	MDA	17475	2.40	0.08	2.41	0.08
SF068	Chub	MS-3(1021)	5-17-73	9-10-11	--	BSFW	--	1.9	N.D.	0.95	0.23
SF069	Chub	MS-3(1021)	5-17-73	12-13-14	--	BSFW	--	2.9	N.D.	2.2	0.33

MONS 204079

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

DRUM

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE ERIE						
MONROE	10-13"	6	.1	.9	.48±.26	tr

FDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
35015	Drum	Monroe	5-4-73	10.9	0.50	FDA	040-979G	0.02	0.00	Trace	0.77
35016	Drum	Monroe	5-4-73	11.2	0.60	FDA	040-980G	Trace	0.00	0.5	0.23
35017	Drum	Monroe	5-4-73	10.2	0.47	FDA	040-981G	Trace	0.00	1.3	0.79
35018	Drum	Monroe	5-4-73	12.9	0.98	FDA	040-982G	0.22	Trace	2.3	0.43
35019	Drum	Monroe	5-4-73	12.9	0.96	FDA	040-983G	0.04	Trace	0.6	0.46
35020	Drum	Monroe	5-4-73	12.8	0.91	FDA	040-984G	0.15	0.02	0.6	0.19

MONS 204081

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

HERRING

Zone	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE SUPERIOR					
MS-2,3	5	2.0±.6	1.8±.8	.10±.02	.03

MONS 204082

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF474	Herring	MS-2(1414)	7-11-73	14.9	--	MDA	17477-A	1.07	0.02	0.80	0.10
SF070	Herring	MS-3(1021)	5-17-73	14.0	--	MDA	17476	2.10	0.04	2.82	0.08
SF071	Herring	MS-3(1021)	5-17-73	12.0	--	MDA	17476	1.86	0.01	1.48	0.11
SF199	Herring	MS-3(1027)	5-10-73	12.0	--	MDA	17475-G	2.56	0.02	1.37	0.12
SF200	Herring	MS-3(1027)	5-10-73	14.0	--	MDA	17475-H	2.40	0.08	2.41	0.08

MONS 204083

-OT-

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

LAKE TROUT

Zone	Number	Size	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
MM-1	1	<17"	1.6	2.2	.20	.02
	2	17-20"	2.2	3.6	.26	.02
MM-3	3	<17"	1.9	2.6	.16	.10
	3	17-20"	1.7	2.4	.21	.06
	3	>20"	6.2	10.6	.42	.14
MM-4	2	<17"	2.3	2.6	.23	.11
	1	17-20"	1.4	1.8	.20	.06
	3	>17"	5.8	8.5	.41	.08
MM-5	3	>17"	4.4	6.8	.36	.06
MM-6	1	17-20"	2.2	6.4	.21	.11
	5	>20"	4.1±2.8	6.3±3.6	.33±.11	.15
MM-7	3	>20"	7.6	11.2	.57	.24
MM-8	3	<17"	1.5	3.4	.17	.08
		>17"	8.3	11.6	.44	.37

MONS 204084

MDA No.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MFO184	Lake Trout	MM-1	5-18-73	16.0	1.4	MDA	13148	1.59	0.02	2.16	0.20
MFO182	Lake Trout	MM-1	5-18-73	19.8	3.0	MDA	13148	1.75	0.03	3.24	0.26
MFO183	Lake Trout	MM-1	5-18-73	19.5	2.6	MDA	13148	2.56	0.01	4.05	0.27
MFO127	Lake Trout	MM-3	6-4-73	16.8	1.9	MDA	13145	1.49	0.12	2.30	0.22
MFO123	Lake Trout	MM-3	4-30-73	16.9	1.5	MDA	11951	2.75	0.13	3.91	0.15
MFO124	Lake Trout	MM-3	4-30-73	16.5	1.5	MDA	11951	1.46	0.05	1.73	0.12
MFO126	Lake Trout	MM-3	6-4-73	18.2	2.5	MDA	13145	1.41	0.05	1.79	0.21
MFO128	Lake Trout	MM-3	6-4-73	18.2	2.4	MDA	13145	1.31	0.07	2.05	0.23
MFO125	Lake Trout	MM-3	4-30-73	17.1	1.7	MDA	11951	2.39	0.06	3.47	0.18
MFO120	Lake Trout	MM-3	4-30-73	30.0	10.6	MDA	11951	6.07	0.14	8.25	0.34
MFO121	Lake Trout	MM-3	4-30-73	28.5	8.7	MDA	11951	7.08	0.15	13.47	0.50
MFO122	Lake Trout	MM-3	4-30-73	28.2	8.0	MDA	11951	5.51	0.13	9.99	0.41
MFO129	Lake Trout	MM-4(S½)	6-27-73	15.8	1.5	MDA	15509	2.14	0.09	2.50	0.22
MFO131	Lake Trout	MM-4(S½)	6-27-73	15.4	1.2	MDA	15509	2.49	0.12	2.75	0.24
MFO130	Lake Trout	MM-4(S½)	6-27-73	18.3	2.0	MDA	15509	1.43	0.06	1.75	0.20
MFO132	Lake Trout	MM-4(S½)	6-27-73	26.7	6.4	MDA	15510	3.89	0.08	7.00	0.40
MFO133	Lake Trout	MM-4(S½)	6-27-73	26.2	6.7	MDA	15510	6.68	0.15	8.75	0.43
MFO134	Lake Trout	MM-4(S½)	6-27-73	28.2	9.7	MDA	15510	6.71	0.02	9.72	0.40
MFO173	Lake Trout	MM-5	5-8-73	27.5	8.0	MDA	11954	4.05	0.02	6.66	0.27
MFO174	Lake Trout	MM-5	5-8-73	24.9	6.0	MDA	11954	3.83	0.08	5.83	0.36
MFO175	Lake Trout	MM-5	5-8-73	27.5	8.5	MDA	11954	5.18	0.08	7.91	0.45
MFO145	Lake Trout	MM-6	8-13-73	18.1	2.1	MDA	18768	2.22	0.11	6.42	0.21
MFO141	Lake Trout	MM-6	8-13-73	26.9	8.2	MDA	18767	8.16	0.28	16.00	0.47
MFO142	Lake Trout	MM-6	8-13-73	25.0	5.5	MDA	18767	2.10	0.18	7.69	0.36
MFO143	Lake Trout	MM-6	8-13-73	27.5	8.4	MDA	18767	6.01	0.17	9.37	0.40
MFO144	Lake Trout	MM-6	8-13-73	20.2	2.9	MDA	18768	2.16	0.07	7.50	0.23
MFO146	Lake Trout	MM-6	8-13-73	20.6	2.5	MDA	18768	2.27	0.07	6.78	0.21

MONS 204085

ID	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
TF0147	Lake Trout	MM-7	8-22-73	28.0	9.0	MDA	18771	6.92	0.23	9.23	0.69
TF0148	Lake Trout	MM-7	8-22-73	28.8	10.4	MDA	18771	9.86	0.27	16.66	0.59
TF0149	Lake Trout	MM-7	8-22-73	25.1	7.3	MDA	18771	5.88	0.23	7.69	0.44
TF0159	Lake Trout	MM-8(N½)	10-1-73	15.2	1.5	MDA	22703	1.58	0.11	4.00	0.16
TF0160	Lake Trout	MM-8(N½)	10-1-73	17.9	1.9	MDA	22703	1.09	0.09	2.75	0.14
TF0161	Lake Trout	MM-8(N½)	10-1-73	17.0	1.6	MDA	22703	1.87	0.04	3.44	0.20
TF0156	Lake Trout	MM-8(N½)	10-1-73	28.1	7.6	MDA	22702	7.13	0.24	10.34	0.43
TF0157	Lake Trout	MM-8(N½)	10-1-73	28.1	9.0	MDA	22702	6.76	0.32	9.48	0.52
TF0158	Lake Trout	MM-8(N½)	10-1-73	28.7	10.1	MDA	22702	10.86	0.56	14.94	0.37

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

LAKE TROUT

Zone	Size	Number	Total DDT's ppm	Total PCB's ppm	Hg ppm	Dieldrin ppm
LAKE SUPERIOR						
MS-1	<17"	4	2.1	2.4	.57	tr
	17-20"	1	2.4	2.9	.51	tr
	>20"	6	7.9±1.4	5.3± .9	.80±.30	.08±.05
MS-2	<17"	3	.3	.5	.18	tr
	17-20"	3	.9	1.8	.36	tr
	>20"	5	1.8± .6	4.2±1.8	.43±.17	.04
MS-3	<17"	12	.9± .7	1.6±1.4	.29±.12	.03
	17-20"	16	1.1± .7	1.9±1.3	.32±.15	.04
	>20"	19	3.3±1.4	4.7±2.2	.69±.27	.06
MS-4	17-20"	6	0.7± .3	1.0± .5	.25±.05	.01
	>20"	15	2.1±1.7	3.3±2.7	.48±.17	.03
MS-5	17-20"	4	.5	.8	.32	.02
	>20"	5	1.5± .2	1.8± .5	.30±.05	.03
MS-6	<17"	3	.6	.9	.21	.01
	17-20"	3	1.0	1.0	.26	.02
	>20"	6	1.4±.3	1.4± .2	.34±.04	.04

MONS 204087

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF 49	Lake Trout	MS-1 (623)	5-11-73	17.3	--	MDA	13135	5.88	0 04	6.42	1.18
SF050	Lake Trout	MS-1 (623)	5-11-73	16.2	--	MDA	13135	1.52	0.04	1.90	0.37
SF051	Lake Trout	MS-1 (623)	5-11-73	14.1	--	MDA	13135	0.67	Trace	0.81	0.41
SF052	Lake Trout	MS-1 (623)	5-11-73	11.5	--	MDA	13135	0.31	Trace	0.27	0.33
SF048	Lake Trout	MS-1 (623)	5-11-73	19.4	--	MDA	13135	2.37	0.02	2.85	0.51
SF044	Lake Trout	MS-1 (623)	5-11-73	33.6	--	MDA	13135	8.90	0.16	5.88	1.44
SF045	Lake Trout	MS-1 (623)	5-11-73	24.4	--	MDA	13135	9.42	0.10	6.61	0.83
SF046	Lake Trout	MS-1 (623)	5-11-73	22.2	--	MDA	13135	7.20	0 07	6.24	0.51
SF047	Lake Trout	MS-1 (623)	5-11-73	23.1	--	MDA	13135	6.99	0.09	4.99	0.90
SF072	Lake Trout	MS-1 (623)	5-11-73	28.7	--	MDA	13135	7.91	0.03	4.57	0.70
SF073	Lake Trout	MS-1 (623)	5-11-73	29.4	--	MDA	13135	6.09	0.04	3.99	0.60
SF074	Lake Trout	MS-1 (623)	5-11-73	27.6	--	MDA	13135	8.54	0.04	4.89	0.59
SF456	Lake Trout	MS-2(1317)	6-22-73	13.2	0.7	MDA	17478	0.08	Trace	0.10	0.18
SF457	Lake Trout	MS-2(1317)	6-22-73	12.0	0.9	MDA	17478	0.32	0.01	0.40	0.16
SF458	Lake Trout	MS-2(1317)	6-22-73	13.3	1.1	MDA	17478	0.56	0.01	0.93	0.21
SF462	Lake Trout	MS-2(1317)	6-22-73	17.7	1.6	MDA	17478	0.56	Trace	1.02	0.40
SF463	Lake Trout	MS-2(1317)	6-22-73	18.9	2.9	MDA	17478	1.06	0.02	1.60	0.34
SF464	Lake Trout	MS-2(1317)	6-22-73	17.5	1.6	MDA	17478	1.13	0.02	2.82	0.34
SF455	Lake Trout	MS-2(1317)	6-22-73	23.8	4.0	MDA	17478	1.74	0.04	4.35	0.17
SF459	Lake Trout	MS-2(1317)	6-22-73	24.0	4.7	MDA	17478	1.11	0.04	1.60	0.39
SF461	Lake Trout	MS-2(1317)	6-22-73	26.9	6.8	MDA	17478	2.59	0.07	6.66	0.60
SF466	Lake Trout	MS-2(1317)	6-22-73	25.1	5.0	MDA	17478	1.36	0.02	3.84	0.40
SF460	Lake Trout	MS-2(1317)	6-22-73	20.6	2.8	MDA	17478	1.99	0.01	4.35	0.57
SF065	Lake Trout	MS-3(1021)	5-17-73	15.2	--	MDA	17476	1.41	0.03	2.22	0.45
SF066	Lake Trout	MS-3(1021)	5-17-73	14.5	--	MDA	17476	1.35	0.02	3.58	0.43
SF067	Lake Trout	MS-3(1021)	5-17-73	13.0	--	MDA	17476	0.81	0.01	1.11	0.29
SF060	Lake Trout	MS-3(1021)	5-17-73	18.2	--	MDA	17476	2.00	0.07	2.75	0.67
SF061	Lake Trout	MS-3(1021)	5-17-73	17.6	--	MDA	17476	1.79	0.07	2.59	0.38
SF063	Lake Trout	MS-3(1021)	5-17-73	18.1	--	MDA	17476	2.64	0.06	3.33	0.57
SF064	Lake Trout	MS-3(1021)	5-17-73	17.0	--	MDA	17476	0.98	0.02	2.05	0.25

MONS 204088

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF421	Lake Trout	MS-3(1130)	4-27-73	28.5	--	MDA	13138	5.05	0.06	6.57	0.55
SF422	Lake Trout	MS-3(1130)	4-27-73	29.7	--	MDA	13138	4.15	0.06	5.35	0.56
SF423	Lake Trout	MS-3(1130)	4-27-73	28.8	--	MDA	13138	5.23	0.03	6.28	0.52
SF442	Lake Trout	MS-3(1323)	5-8-73	19.7	--	MDA	13140	0.57	0.01	0.55	0.25
SF443	Lake Trout	MS-3(1323)	5-8-73	19.9	--	MDA	13140	0.63	Trace	0.83	0.26
SF444	Lake Trout	MS-3(1323)	5-8-73	17.3	--	MDA	13140	0.77	0.01	1.11	0.24
SF439	Lake Trout	MS-3(1323)	5-8-73	28.5	--	MDA	13140	2.31	0.03	2.22	0.53
SF440	Lake Trout	MS-3(1323)	5-8-73	28.6	--	MDA	13140	5.78	0.08	5.55	0.83
SF441	Lake Trout	MS-3(1323)	5-8-73	29.7	--	MDA	13140	2.37	0.04	2.22	0.61
	Lake Trout	MS-4(1533)		19.9		MDA		0.71	0.02	1.72	0.30
	Lake Trout	MS-4(1533)		19.9		MDA		0.50	0.02	0.70	0.31
	Lake Trout	MS-4(1533)		19.9		MDA		0.28	0.01	0.45	0.23
	Lake Trout	MS-4(1533)		19.0		MDA		0.98	0.01	0.81	0.23
	Lake Trout	MS-4(1533)		18.7		MDA		2.57	0.01	0.81	0.23
	Lake Trout	MS-4(1533)		18.1		MDA		0.92	0.01	1.62	0.18
	Lake Trout	MS-4(1533)		22.5		MDA		0.38	0.02	0.45	0.24
	Lake Trout	MS-4(1533)		24.9		MDA		1.24	0.02	1.74	0.50
	Lake Trout	MS-4(1533)		22.9		MDA		1.25	0.05	2.40	0.27
	Lake Trout	MS-4(1533)		26.6		MDA		5.93	0.06	7.20	0.80
	Lake Trout	MS-4(1533)		29.5		MDA		2.32	0.05	2.80	0.45
	Lake Trout	MS-4(1533)		27.8		MDA		1.77	0.04	2.80	0.47
	Lake Trout	MS-4(1533)		30.0		MDA		4.54	0.02	8.53	0.59
	Lake Trout	MS-4(1533)		29.6		MDA		2.10	0.04	4.16	0.55
	Lake Trout	MS-4(1533)		29.0		MDA		4.33	0.01	8.33	0.68
	Lake Trout	MS-4(1533)		28.4		MDA		2.00	0.02	3.74	0.61
	Lake Trout	MS-4(1533)		27.1		MDA		3.08	0.01	3.24	0.67
	Lake Trout	MS-4(1533)		26.4		MDA		1.02	0.02	1.85	0.44
	Lake Trout	MS-4(1533)		22.9		MDA		0.43	0.02	0.81	0.30
	Lake Trout	MS-4(1533)		21.3		MDA		0.55	0.02	0.92	0.25
	Lake Trout	MS-4(1533)		21.0		MDA		0.69	0.01	0.81	0.43

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF035	Lake Trout	MS-5(1440)	5-11-73	19.0	--	MDA	13130	0.50	0.02	0.78	0.29
SF036	Lake Trout	MS-5(1440)	5-11-73	19.9	--	MDA	13130	0.46	0.02	0.72	0.31
SF037	Lake Trout	MS-5(1440)	5-11-73	19.9	--	MDA	13130	0.61	0.04	0.90	0.30
SF038	Lake Trout	MS-5(1440)	5-11-73	21.8	--	MDA	13130	0.47	0.02	0.72	0.37
SF039	Lake Trout	MS-5(1440)	5-11-73	23.0	--	MDA	13130	1.45	0.02	1.51	0.38
SF040	Lake Trout	MS-5(1440)	5-11-73	24.9	--	MDA	13130	1.34	0.03	1.51	0.32
SF041	Lake Trout	MS-5(1440)	5-11-73	28.5	--	MDA	13130	1.80	0.05	2.12	0.26
SF042	Lake Trout	MS-5(1440)	5-11-73	26.2	--	MDA	13130	1.27	0.03	1.21	0.27
SF043	Lake Trout	MS-5(1440)	5-11-73	26.8	--	MDA	13130	1.56	0.04	2.41	0.29
SF023	Lake Trout	MS-6(1444)	5-10-73	16.2	--	MDA	13133	0.54	0.01	0.88	0.24
SF024	Lake Trout	MS-6(1444)	5-10-73	14.4	--	MDA	13133	0.43	0.01	0.58	0.19
SF025	Lake Trout	MS-6(1444)	5-10-73	15.2	--	MDA	13133	0.73	0.02	1.17	0.21
SF026	Lake Trout	MS-6(1444)	5-10-73	17.5	--	MDA	13133	0.85	0.02	0.88	0.26
SF027	Lake Trout	MS-6(1444)	5-10-73	17.8	--	MDA	13133	0.84	0.02	0.88	0.28
SF028	Lake Trout	MS-6(1444)	5-10-73	19.1	--	MDA	13133	1.17	0.03	1.17	0.24
SF029	Lake Trout	MS-6(1444)	5-10-73	22.4	--	MDA	13133	1.60	0.04	1.47	0.32
SF030	Lake Trout	MS-6(1444)	5-10-73	23.4	--	MDA	13133	1.38	0.03	1.72	0.36
SF031	Lake Trout	MS-6(1444)	5-10-73	23.0	--	MDA	13133	1.14	0.03	1.21	0.29
SF032	Lake Trout	MS-6(1444)	5-10-73	28.0	--	MDA	13133	1.39	0.04	1.21	0.31
SF033	Lake Trout	MS-6(1444)	5-10-73	27.4	--	MDA	13133	1.02	0.04	1.21	0.34
SF034	Lake Trout	MS-6(1444)	5-10-73	29.7	--	MDA	13133	1.67	0.03	1.51	0.40

MONS 204090

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF054	Lake Trout	MS-3(1021)	5-17-73	27.0	--	MDA	17476	2.96	0.09	8.62	1.24
SF055	Lake Trout	MS-3(1021)	5-17-73	22.5	--	MDA	17476	3.44	0.08	4.82	0.88
SF056	Lake Trout	MS-3(1021)	5-17-73	25.6	--	MDA	17476	4.98	0.05	6.89	1.18
SF057	Lake Trout	MS-3(1021)	5-17-73	24.4	--	MDA	17476	5.30	0.13	7.58	0.91
SF058	Lake Trout	MS-3(1021)	5-17-73	21.8	--	MDA	17476	3.20	0.12	3.94	0.86
SF059	Lake Trout	MS-3(1021)	5-17-73	20.4	--	MDA	17476	2.79	0.06	3.44	0.73
SF062	Lake Trout	MS-3(1021)	5-17-73	21.5	--	MDA	17476	2.65	0.07	8.46	1.08
SF191	Lake Trout	MS-3(1127)	5-10-73	16.8	--	MDA	17475	2.54	0.14	4.88	0.55
SF192	Lake Trout	MS-3(1127)	5-10-73	14.5	--	MDA	17475	1.13	0.07	2.32	0.23
SF193	Lake Trout	MS-3(1127)	5-10-73	12.3	--	MDA	17475	0.46	0.01	0.69	0.21
SF194	Lake Trout	MS-3(1127)	5-10-73	18.7	--	MDA	17475	1.11	0.10	3.95	0.46
SF195	Lake Trout	MS-3(1127)	5-10-73	17.2	--	MDA	17475	2.11	0.07	3.72	0.47
SF196	Lake Trout	MS-3(1127)	5-10-73	17.0	--	MDA	17475	1.86	0.08	3.72	0.37
SF430	Lake Trout	MS-3(1122)	5-8-73	13.6	--	MDA	13134	0.46	Trace	0.83	0.28
SF431	Lake Trout	MS-3(1122)	5-8-73	15.8	--	MDA	13134	0.58	0.01	0.83	0.22
SF432	Lake Trout	MS-3(1122)	5-8-73	16.9	--	MDA	13134	0.64	Trace	1.11	0.25
SF433	Lake Trout	MS-3(1122)	5-8-73	19.0	--	MDA	13134	0.74	0.02	0.88	0.23
SF434	Lake Trout	MS-3(1122)	5-8-73	18.6	--	MDA	13134	1.05	0.03	0.88	0.25
SF435	Lake Trout	MS-3(1122)	5-8-73	19.0	--	MDA	13134	1.09	0.03	1.17	0.23
SF436	Lake Trout	MS-3(1122)	5-8-73	28.4	--	MDA	13134	1.93	0.04	2.35	0.36
SF437	Lake Trout	MS-3(1122)	5-8-73	30.4	--	MDA	13134	3.35	0.05	4.82	0.58
SF438	Lake Trout	MS-3(1122)	5-8-73	28.5	--	MDA	13134	1.64	0.03	2.41	0.41
SF075	Lake Trout	MS-3(1122)	5-8-73	22.0	--	MDA	13134	2.32	0.02	3.44	0.53
SF076	Lake Trout	MS-3(1122)	5-8-73	23.8	--	MDA	13134	1.86	0.04	2.75	0.34
SF077	Lake Trout	MS-3(1122)	5-8-73	24.9	--	MDA	13134	1.88	0.05	1.76	0.38
SF427	Lake Trout	MS-3(1130)	4-27-73	15.5	--	MDA	13138	0.17	0.01	0.28	0.20
SF428	Lake Trout	MS-3(1130)	4-27-73	16.6	--	MDA	13138	0.25	0.01	0.39	0.17
SF429	Lake Trout	MS-3(1130)	4-27-73	16.4	--	MDA	13138	0.49	N.D.	0.75	0.15
SF424	Lake Trout	MS-3(1130)	4-27-73	17.9	--	MDA	13138	0.37	0.03	0.85	0.20
SF425	Lake Trout	MS-3(1130)	4-27-73	19.7	--	MDA	13138	0.43	0.01	0.85	0.15
SF426	Lake Trout	MS-3(1130)	4-27-73	19.2	--	MDA	13138	0.39	0.01	0.57	0.14

MONS 204091

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

MENOMINEE

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
MM-5	—	6	.7+.2	1.0±.6	.06±.04	.02
LAKE HURON						
MH-1 (N½)	--	6	.4±.2	.4±.2	.03	.03

MONS 204092

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MF0185	Menominee	MH-1(N½)	4-24-73	16.2	1.4	MDA	10496	0.61	0.03	0.66	0.04
MF0186	Menominee	MH-1(N½)	4-24-73	16.2	1.5	MDA	10496	0.38	0.06	0.33	0.02
MF0187	Menominee	MH-1(N½)	4-24-73	17.1	1.7	MDA	10496	0.42	0.01	0 41	0.03
MF0188	Menominee	MH-1(N½)	4-24-73	13.0	0.7	MDA	10496	0.28	0.03	0.24	0.02
MF0189	Menominee	MH-1(N½)	4-24-73	12.7	0.6	MDA	10496	0.23	0.02	0.24	0.02
MF0190	Menominee	MH-1(N½)	4-24-73	13.4	0.7	MDA	10496	0.21	0.02	0.33	0.02

MONS 204093

FDA SO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
30167	Menominee	MM-5	5-7-73	13.2	0.7	MDA	11952	0.58	0.03	0.65	0.02
30168	Menominee	MM-5	5-7-73	13.3	0.7	MDA	11952	0.33	0.01	0.34	0.03
30169	Menominee	MM-5	5-7-73	12.6	0.6	MDA	11952	0.46	0.03	0.72	0.04
30170	Menominee	MM-5	5-7-73	17.2	0.8	MDA	11953	0.92	Trace	1.68	0.10
30171	Menominee	MM-5	5-7-73	16.4	1.6	MDA	11953	0.73	0.02	1.20	0.11
30172	Menominee	MM-5	5-7-73	16.9	1.5	MDA	11953	0.92	0.02	1.68	0.06

MONS 204094

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

YELLOW PERCH

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
MM-8	8-10"	6	.1+.08	.4±.2	.12±.04	tr
LAKE HURON						
MH-1 (N½)		6	.1	.2	.16	.01
LAKE ERIE						
MONROE	<9"	3	tr	.2	.40	0
	>9"	3	tr	tr	.55	0
LAKE ST. CLAIR						
STATION 4	<8"	5	0	tr	.25±.04	0
	>8"	3	1.3	2.2	.52	tr

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MF0150	Y.Perch	MM-8(N½)	9-26-73	10.6	0.5	MDA	22704	0.29	0.03	0.56	0.18
MF0151	Y.Perch	MM-8(N½)	9-26-73	9.3	0.4	MDA	22704	0.17	0.03	0.61	0.08
MF0152	Y.Perch	MM-8(N½)	9-26-73	10.3	0.5	MDA	22704	0.12	0.01	0.42	0.14
MF0153	Y.Perch	MM-8(N½)	9-26-73	8.5	0.2	MDA	22704	0.09	Trace	0.25	0.11
MF0154	Y.Perch	MM-8(N½)	9-26-73	8.3	0.3	MDA	22704	0.05	Trace	0.18	0.10
MF0155	Y.Perch	MM-8(N½)	9-26-73	8.7	0.3	MDA	22704	0.13	Trace	0.49	0.09

MONS 204096

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
HFO354	Perch	MH-1(N½)	10-4-73	7.8)							
HFO354	Perch	MH-1(N½)	10-4-73	7.9)	Fillets	MDA	24262	0.08	0.01	0.24	0.15
HFO354	Perch	MH-1(N½)	10-4-73	8.6)							
HFO355	Perch	MH-1(N½)	10-4-73	12.6)							
HFO355	Perch	MH-1(N½)	10-4-73	9.8)	Fillets	MDA	24262	0.07	0.01	0.20	0.17
HFO355	Perch	MH-1(N½)	10-4-73	9.5)							

MONS 204097

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FDA NO.	SPECIES	LOCATION	DATE	LENGTH	HEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3E005	Y. Perch	Monroe	5-4-73	7.3	0.16	FDA	040-969G	0.00	0.00	Trace	0.39
3E006	Y. Perch	Monroe	5-4-73	8.5	0.26	FDA	040-970G	Trace	0.00	0.4	0.39
3E007	Y. Perch	Monroe	5-4-73	8.1	0.28	FDA	040-971G	Trace	0.00	0.3	0.42
3E008	Y. Perch	Monroe	5-4-73	10.6	0.60	FDA	040-972G	Trace	0.00	Trace	0.61
3E009	Y. Perch	Monroe	5-4-73	9.2	0.37	FDA	040-973G	0.00	0.00	Trace	0.43
3E010	Y. Perch	Monroe	5-4-73	10.1	0.52	FDA	040-974G	0.00	0.00	Trace	0.61

MONS 204098

NOA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3C016	Y. Perch	Sta. 4	5-31-73	7.3	0.13	FDA	108-216G	0.00	0.00	0.0	0.30
3C017	Y. Perch	Sta. 4	5-31-73	7.9	0.20	FDA	108-217G	0.00	0.00	Trace	0.29
3C021	Y. Perch	Sta. 4	6-1-73	7.2	0.17	FDA	040-961G	0.00	0.00	0.0	0.22
3C022	Y. Perch	Sta. 4	6-1-73	7.1	0.19	FDA	040-962G	0.00	0.00	Trace	0.22
3C023	Y. Perch	Sta. 4	6-1-73	7.3	0.18	FDA	040-963G	0.00	0.00	0.0	0.21
3C018	Y. Perch	Sta. 4	5-31-73	9.6	0.33	FDA	108-218G	Trace	0.00	Trace	0.56
3C019	Y. Perch	Sta. 4	5-31-73	9.5	0.32	FDA	108-219G	2.46	0.06	3.8	0.61*
3C020	Y. Perch	Sta. 4	5-31-73	9.3	0.36	FDA	108-220G	0.08	0.00	0.6	0.41

*Trace of Endrin

MONS 204099

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

SALMON

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
-Chinook- MM-5	--	2	3.6	6.4	.58	.09
-Coho- MM-5	--	2	2.9	4.9	.37	.18
LAKE HURON						
MH-1	--	1	2.5	4.2	.40	.01
MH-3	--	5	5.8±1.5	9.2±2.4	.27±.05	.20±.02

MONS 204100

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
C-45994	Chinook	MM-5	--	--	--	MDA	24259	2.63	0.12	4.99	0.52
C-45993	Chinook	MM-5	--	--	19.0	MDA	24258	4.66	0.05	7.90	0.64
C-45995	Coho	MM-5	--	--	6.0	MDA	24260	2.68	0.14	4.44	0.39
C-45996	Coho	MM-5	--	--	6.0	MDA	24261	3.10	0.22	5.33	0.34

MONS 204101

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
HF0348	Chinook	MH3	9-5-73	31.6	16.0	MDA	20028	4.23	0.19	7.50	0.25
HF0349	Chinook	MH3	9-5-73	30.6	13.6	MDA	20028	5.46	0.20	8.57	0.23
HF0350	Chinook	MH3	9-5-73	31.7	14.5	MDA	20028	4.64	0.19	7.33	0.30
HF0351	Chinook	MH3	9-5-73	38.5	25.4	MDA	20028	7.97	0.23	13.14	0.24
HF0352	Chinook	MH3	9-5-73	38.1	23.3	MDA	20028	6.45	0.20	9.60	0.34
HF C-43577	Coho	Nagel's Cr. MH1	2-21-73	Fillets 3½	—	MDA	2125	2.52	0.01	4.16	0.40

MONS 204102

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

SMELT

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN						
MM-1	--	3	.8	1.6	.09	.03
LAKE HURON						
MH-3	--	2	.5	.6	.12	.02

MONS 204103

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MF0176	Smelt	MM-1	5-17-73	Finger Group	0.6	MDA	13146	0.97	0.01	2.11	0.08
MF0177	Smelt	MM-1	5-17-73	Finger Group	0.6	MDA	13146	0.67	0.05	1.08	0.09
MF0178	Smelt	MM-1	5-17-73	Finger Group	0.6	MDA	13146	0.72	0.03	1.59	0.09

MONS 204104

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
HF0191	Smelt	MH-3(AuSable)	6-14-73	--	Approx.3 lbs.	MDA	15511	0.41	Trace	0.54	0.10
HF0192	Smelt	MH-3	8-23-73	Varied	250 g.	MDA	20027	0.57	0.04	0.64	0.15

MONS 204105

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

SUCKERS

Zone		Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE MICHIGAN							
MM-1	(LN)	12-13"	3	.5	.7	.06	.05
	(WH)	17-18"	3	.1	.2	.21	tr

MONS 204106

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MFO179	Suckers(LN)	MM-1	5-17-73	12.6	1.6	MDA	13147	0.55	0.05	0.74	0.08
MFO181	Suckers(LN)	MM-1	5-17-73	12.7	1.7	MDA	13147	0.57	0.05	0.81	0.04
MFO180	Suckers(LN)	MM-1	5-17-73	12.6	1.6	MDA	13147	0.47	0.04	0.62	0.06
MFO185	Suckers(Wh.)	MM-1	5-23-73	17.8	2.4	MDA	13149	0.06	N.D.	0.18	0.23
MFO186	Suckers(Wh.)	MM-1	5-23-73	17.9	2.2	MDA	13149	0.12	0.01	0.25	0.23
MFO187	Suckers(Wh.)	MM-1	5-23-73	17.6	1.9	MDA	13149	0.12	N.D.	0.18	0.21

MONS 204107

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

WALLEYE

Zone	Site	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE HURON						
MH-1 (N½)	--	6	.9±1.3	1.1±1.4	.55±.36	.03
LAKE ERIE						
MONROE	--	6	.04	.5	.56±.16	tr
LAKE ST. CLAIR						
STATION 4	--	6	.3	.4	1.11±.46	tr

MONS 204108

MDA No.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
HFO356	Walleye	MH-1(N½)	10-4-73	23.5	--	MDA	24263	0.55	0.04	0.74	1.05
HFO357	Walleye	MH-1(N½)	10-4-73	21.5	--	MDA	24263	3.60	0.08	3.74	0.80
HFO358	Walleye	MH-1(N½)	10-4-73	20.3	--	MDA	24263	0.93	0.02	1.24	0.76
HFO359	Walleye	MH-1(N½)	10-4-73	14.2	--	MDA	24263	0.16	0.01	0.16	0.23
HFO360	Walleye	MH-1(N½)	10-4-73	15.4	--	MDA	24263	0.14	0.01	0.16	0.26
HFO361	Walleye	MH-1(N½)	10-4-73	14.7	--	MDA	24263	0.21	0.05	0.41	0.22

MONS 204109

FDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3E000	Walleye	Monroe	5-4-73	15.8	1.38	FDA	040-964G	0.03	Trace	0.4	0.87
3E002	Walleye	Monroe	5-4-73	14.4	1.02	FDA	040-966G	0.02	Trace	0.3	0.42
3E003	Walleye	Monroe	5-4-73	20.1	3.07	FDA	040-967G	0.03	Trace	0.6	0.44
3E004	Walleye	Monroe	5-4-73	18.0	2.13	FDA	040-968G	0.05	Trace	0.6	0.52
3E021	Walleye	Monroe	5-4-73	18.4	2.37	FDA	040-991G	0.07	Trace	0.6	0.52
3E001	Walleye	Monroe	5-4-73	13.8	0.88	FDA	040-965G	0.03	Trace	0.4	0.56

MONS 204110

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MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3C001	Walleye	Sta. 4	5-29-73	14.3	0.95	FDA	108-201G	Trace	Trace	Trace	0.61
3C002	Walleye	Sta. 4	5-29-73	14.0	0.91	FDA	108-202G	Trace	0.00	0.03	0.46
3C003	Walleye	Sta. 4	5-29-73	14.0	0.88	FDA	108-203G	Trace	0.00	Trace	1.23
3C004	Walleye	Sta. 4	5-29-73	19.0	2.04	FDA	108-204G	0.21	0.01	0.7	1.43
3C005	Walleye	Sta. 4	5-29-73	19.4	2.32	FDA	108-205G	1.19	0.01	1.3	1.58
3C006	Walleye	Sta. 4	5-29-73	19.2	2.36	FDA	108-206G	0.19	Trace	0.4	1.34

MONS 204111

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

WHITE BASS

Zone	Size	Number	Total DDT's ppm	PCB's ppm	Hg ppm	Dieldrin ppm
LAKE ERIE MONROE		4	.3	2.5	.54	.01

MONS 204112

FDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
3E011	Wh. Bass	Monroe	5-4-73	8.7	0.3	FDA	040-975G	0.16	0.01	2.0	0.40
3E012	Wh. Bass	Monroe	5-4-73	10.3	0.52	FDA	040-976G	0.03	0.00	0.5	0.29
3E013	Wh. Bass	Monroe	5-4-73	11.6	0.79	FDA	040-977G	0.37	0.01	3.5	0.81
3E014	Wh. Bass	Monroe	5-4-73	11.8	0.82	FDA	040-978G	0.43	0.02	1.5	0.66

MONS 204113

SUMMARY OF 1973 GLECS DATA

Prepared by the Michigan Department of Agriculture

WHITEFISH

Zone	Number	Total DDT's ppm	Total PCB's ppm	Hg ppm	Dieldrin ppm
LAKE SUPERIOR					
MS-3	6	.5±.2	.5±.2	.11±.02	.06
MS-6	9	.2±.1	.2±.1	.12±.08	.01
LAKE MICHIGAN					
MM-1	3	.9	.9	.07	.12
LAKE HURON					
MH-1	18	.6±.3	.5±.2	.07±.07	.09

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
SF448	Whitefish	MS-3(1026)	5-9-73	18.5	---	MDA	13137	0.34	0.02	0.43	0.14
SF449	Whitefish	MS-3(1026)	5-9-73	19.5	---	MDA	13137	0.37	0.06	0.37	0.11
SF450	Whitefish	MS-3(1026)	5-9-73	19.0	---	MDA	13137	0.30	0.06	0.30	0.10
SF451	Whitefish	MS-3(1026)	5-9-73	22.0	---	MDA	13137	0.66	0.10	0.57	0.11
SF452	Whitefish	MS-3(1026)	5-9-73	24.2	---	MDA	13137	0.66	0.06	0.74	0.10
SF453	Whitefish	MS-3(1026)	5-9-73	24.6	---	MDA	13137	0.75	0.05	0.68	0.12
SF014	Whitefish	MS-6(1544)	5-10-73	16.9	---	MDA	13139	0.11	0.02	0.20	0.05
SF015	Whitefish	MS-6(1544)	5-10-73	16.5	---	MDA	13139	0.12	0.03	0.25	0.08
SF016	Whitefish	MS-6(1544)	5-10-73	16.2	---	MDA	13139	0.18	0.01	0.25	0.10
SF017	Whitefish	MS-6(1544)	5-10-73	18.7	---	MDA	13139	0.22	N.D.	0.30	0.09
SF018	Whitefish	MS-6(1544)	5-10-73	19.6	---	MDA	13139	0.14	N.D.	0.11	0.13
SF019	Whitefish	MS-6(1544)	5-10-73	18.7	---	MDA	13139	0.17	0.01	0.17	0.08
SF020	Whitefish	MS-6(1544)	5-10-73	22.3	---	MDA	13139	0.23	0.01	0.29	0.12
SF021	Whitefish	MS-6(1544)	5-10-73	21.6	---	MDA	13139	0.32	N.D.	0.23	0.12
SF022	Whitefish	MS-6(1544)	5-10-73	22.3	---	MDA	13139	0.25	0.01	0.29	0.32

MONS 204115

MDA NO	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT'S	DIELDRIN	PCB'S	MERCURY
MF0188	Whitefish	MM-1	5-24-73	18.1	2.5	MDA	13150	1.11	0.19	1.15	0.07
MF0189	Whitefish	MM-1	5-24-73	19.5	2.7	MDA	13150	0.74	0.10	0.72	0.07
MF0190	Whitefish	MM-1	5-24-73	--	--	MDA	13150	0.83	0.08	0.90	0.07

MONS 204116

MDA NO.	SPECIES	LOCATION	DATE	LENGTH	WEIGHT	ANALYZED BY	LAB. NO.	TOTAL DDT's	DIELDRIN	PCB'S	MERCURY
MFO167	Whitefish	MH-1(S½)	4-19-73	20.0	3.1	MDA	10491	0.64	0.11	0.58	0.10
MFO170	Whitefish	MH-1(S½)	4-19-73	15.2	1.2	MDA	10491	0.35	0.06	0.41	0.03
MFO171	Whitefish	MH-1(S½)	4-19-73	12.0	0.7	MDA	10491	0.37	0.05	0.41	0.02
MFO172	Whitefish	MH-1(S½)	4-19-73	10.2	0.4	MDA	10492	0.16	Trace	0.33	0.02
MFO173	Whitefish	MH-1(S½)	4-19-73	17.1	1.9	MDA	10492	0.23	0.07	0.33	0.37
MFO174	Whitefish	MH-1(S½)	4-19-73	19.2	2.4	MDA	10492	0.32	0.04	0.33	0.05
MFO175	Whitefish	MH-1(S½)	4-19-73	17.3	2.2	MDA	10492	0.34	0.06	0.32	0.04
MFO168	Whitefish	MH-1(S½)	4-19-73	20.2	3.2	MDA	10491	0.38	0.05	0.33	0.04
MFO169	Whitefish	MH-1(S½)	4-19-73	20.2	3.6	MDA	10491	0.56	0.08	0.49	0.05
MFO179	Whitefish	MH-1(N½)	4-24-73	19.5	2.6	MDA	10494	0.44	0.08	0.40	0.05
MFO180	Whitefish	MH-1(N½)	4-24-73	18.6	2.6	MDA	10494	0.55	0.08	0.48	0.07
MFO181	Whitefish	MH-1(N½)	4-24-73	17.6	2.0	MDA	10494	0.65	0.10	0.56	0.04
MFO182	Whitefish	MH-1(N½)	4-24-73	16.1	1.5	MDA	10495	0.50	0.04	0.48	0.04
MFO183	Whitefish	MH-1(N½)	4-24-73	15.3	2.2	MDA	10495	0.51	0.03	0.58	0.08
MFO184	Whitefish	MH-1(N½)	4-24-73	16.3	1.7	MDA	10495	0.63	0.05	0.66	0.03
MFO176	Whitefish	MH-1(N½)	4-24-73	23.3	4.2	MDA	10493	1.11	0.13	0.80	0.07
MFO177	Whitefish	MH-1(N½)	4-24-73	23.8	4.5	MDA	10493	0.93	0.10	0.64	0.06
MFO178	Whitefish	MH-1(N½)	4-24-73	22.9	4.7	MDA	10493	1.37	0.51	1.12	0.06

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POLYCHLORINATED BIPHENYLS IN MICHIGAN WATERS

Report to WRC Comm

June 1973

MAY 28 1974

The Bureau of Water Management's last progress report to the Commission on the PCB situation was in December, 1971. Some of you have requested an updating. That is the purpose of this report today.

Since the last briefing to you, EPA has come out with a recommendation that receiving waters should not contain PCB's in excess of 0.01 ppb. Such a low level was deemed necessary in view of the fact that research has demonstrated biomagnification of PCB's in fish can be as high as 200,000 times the concentration in water to which they are exposed. There is an indication now that EPA may even lower their recommended level by adopting the recommendation of 0.002 ppb made in the upcoming edition of Water Quality Criteria (NAS, 1972), commonly referred to as the "Blue Book". Anyway, the EPA recommendation of 0.01 ppb for receiving waters has provided us with a guideline to use in reference to our monitoring programs.

As you may recall, Michigan instituted a monitoring program for polychlorinated biphenyls (PCB's) early in 1971. The initial program consisted of a state-wide water sampling survey for determination of concentrations in inland waters and tributaries to the Great Lakes. Supplementary sampling has since been conducted on stream sediments, municipal raw water intakes, groundwater drinking supplies, sanitary landfill runoffs, municipal wastewater treatment plants, industrial discharges, and fish from both inland and Great Lakes waters. Sampling is being continued in tributary streams, wastewater treatment plants, and in fish on a periodic basis as a means of following the effectiveness of control and reduction programs.

Water sampling in thirty Michigan tributaries during 1971 and 1972 showed that about 60 percent of the samples exceeded the 0.01 ppb guideline with one stream, the Saginaw River, having a high concentration of 2.9 ppb (Table 1). It is interesting to note that fish from the Saginaw River were found to have PCB concentrations as high as 165 ppm (Table 2). Five Michigan streams had mean concentrations in water samples over 0.10 ppb, 10 times higher than the EPA guideline. These were the Saginaw, Tittebawassee, Clinton, Raisin and Rouge Rivers, all located in the populous southeastern lower peninsula which drains into lower Lake Huron, Lake St. Clair and Lake Erie. Of the Lake Michigan streams, the Grand and Kalamazoo rivers consistently showed the highest concentrations with means of 0.041 and 0.065 ppb, respectively.

In May, 1973 (just last month) we sampled the water in the Lower Peninsula tributaries again and found just 8 (36 percent) exceeding the 0.01 ppb guideline (Table 3). This is an apparent improvement over previous years which we hope is the beginning of a downward trend. Improvements were especially noted in the Saginaw, Tittabawassee, and Raisin Rivers.

Sampling of municipal wastewater treatment plant (WWTP) effluents throughout Michigan in 1971 and 1972 indicated that many WWTP's represent major point sources of PCB loss to surface waters (Table 4). The average PCB concentration of 60 effluents sampled was 2.55 ppb. While only seven of the WWTP effluents exceeded 1 ppb, the Bay City WWTP located on the Saginaw River had an average effluent concentration of 170 ppb (high of 340 ppb), skewing the over-all average for all plants sharply upward. The average concentration excluding the Bay

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were, with one exception, located on rivers already identified as having levels of PCB contamination. One would tend to believe that if industrial has been decreased, it would be reflected first in reduced concentrations charges from wastewater treatment plants. Sampling of 58 WWTP effluents however, continues to show high PCB levels with an average concentration ppb (Table 5), including the Bay City plant. Although still high, that the PCB discharge from the Bay City WWTP has been greatly reduced.

pling of sewage sludge from 57 of the 58 WWTP's tested in 1973 showed ity to have the highest concentration of PCB's in the sludge being removed treatment process. The PCB concentration in the sludge from the Bay plant was 352 ppm (dry weight basis) compared to a state-wide average of ppm (Table 6).

In an attempt to identify major contributors of PCB's within municipal systems, sampling at key points in the interceptor systems has been ted within the municipalities of Bay City, Mt. Clemens, Saginaw, Adrian, and Kalamazoo. This program has been very successful in that it has tified numerous PCB sources. In most cases, our agency has contacted the tries identified and have asked for corrective action. The City of Detroit, ver, has taken its own initiative and is getting good cooperation. Two of major sources identified in the Detroit system have completed a changeover on-PCB products and the other two are underway.

A broad scale sampling of industrial discharges throughout Michigan has shown lts indicative of the widespread usage of PCB's. Nearly half of the industrial harges sampled have contained more than 0.1 ppb with many in excess of 1 ppb. highest concentration detected in an industrial discharge in Michigan has 7,200 ppb and this was just found recently. Automotive plants, chemical nts, and paper product manufacturers are among the types of industries with st concentrations. Also industries and building complexes, including some ls and hospitals, with heat transfer systems appear to be another major source. tries identified as sources of PCB pollution have been encouraged to change placement compounds or to clean up their operation so that discharges of are eliminated. Our sampling of industries generally has shown that even h Monsanto Company (the only U.S. manufacturer of PCB's) has stopped the of PCB's for all uses except electrical transformers and capacitors, many tries apparently have large enough stock piles of PCB for replacement that have not yet been forced into switching to substitute compounds. We view ontinuing search for sources as a necessity so that we can speed up the geover process. There are some indications that even after an industry the use of PCB's a residual is going to continue in their effluent for iderable length of time until the sewers can be completely flushed out.

are encouraged that some rivers are starting to show reductions in PCB trations. An example of one location in Michigan where monitoring and quent control measures have resulted in a marked reduction in PCB contamination Saginaw River basin. Monitoring of major Great Lakes tributaries during 1972 identified the Saginaw River as having the highest concentrations of of any tributary within Michigan boundaries. Intensive sampling throughout iver basin in search of point sources successfully isolated ten major points discharge to the river system. Each of the industrial sources were asked ntify the cause of their losses and to take corrective action. The following listing of the point sources and corrective actions taken to this date:

evrolet Bay City Parts Plant - PCB's had been used as hydraulic fluids in the die-cast machines. Losses were occurring both in the cooling

Our last report from General Motors showed conversion to a phosphate-ester based compound about 50 percent completed.

Bay City WWTP - Interceptor sampling identified the Chevrolet Parts Plant as the major contributor to this sytem. Since the initial steps of the General Motors plant conversion away from PCB fluids, the PCB levels in the WWTP effluent have dropped to about 1 percent of the previous highs.

General Motors Grey Iron and Nodular Iron Foundries, Saginaw - The problem here was also related to losses of hydraulic fluids. Conversion to phosphate ester fluids is reported to be complete.

Saginaw WWTP - Concentrations of PCB's in the effluent were not nearly as high as in the Bay City Plant. The Grey Iron and Nodular Iron Foundries were identified as the major contributors to the system. Concentrations in the WWTP effluent have declined to about 50 percent of their previous levels.

Buick Motors, Flint - This plant was using PCB's as hydraulic fluids in 13 die cast machines. Conversion to a phosphate ester-glycol product was completed November 1, 1972.

Chevrolet Van Slyke Engine Plant, Flint - A coolant containing PCB's has been replaced with a substitute product.

Flint WWTP - Concentrations have steadily declined since our 1st sampling period in the fall of 1971 and now are considered very low.

Dow Corning Company, Midland - PCB's have been used in the heat transfer systems at this plant. Conversion to a substitute fluid is 50 percent complete.

Dow Corning Semiconductor Products Plant, Hemlock - Conversion of heat transfer fluids was completed in January, 1973.

Voluntary conversion to non-PCB containing products is proving to be very effective toward lowering the PCB concentrations in the Saginaw River. If you will refer to Table 7 of your written report you will note a sharp decline at our monitoring site near the river mouth in October, 1972. Concentrations have remained fairly low ever since that date with the exception of the sample from last month which indicated an increase back up to 0.2 ppb. Overall the situation appears to have improved considerably and we hope that a corresponding decline in PCB concentrations in fish from the river and the Saginaw Bay will soon be observed.

You may recall that in May, 1972 we reported to you about a PCB situation in the Kalamazoo River. During our intensive water quality and biological survey of the Kalamazoo watershed we discovered sharp increases in PCB's in fish below the municipalities of Battle Creek and Kalamazoo. Follow up surveys were unsuccessful at identifying any major sources in Battle Creek but in the Kalamazoo vicinity surveys have pointed the finger at both past and present wastepaper recycling operations by the paper industry. Certain sediment deposits in an impoundment on Portage Creek, a tributary to the Kalamazoo River, were found to contain PCB's at concentrations exceeding 350 ppm (dry weight basis). Leaching

from these PCB enriched sediments appears to be significant. During a drawdown of the impoundment last summer, scouring of the bottom sediments occurred and a sharp rise in PCB levels in river water was observed as the sediments moved downstream. As a result of sampling within the WWTP interceptor system, it is apparent to us that the remaining de-inking operations are still contributing to the PCB contamination problem. We are not sure what the solution to this problem might be because it would obviously involve a policy decision at the National level about the merits of recycling paper.

In 1972 Michigan developed a cooperative State-Federal study of contaminant levels in Great Lakes fish species including lake trout, salmon, whitefish, chubs, menominee, yellow perch, alewife, carp, and suckers. Fish from Lakes Michigan, Huron, Erie, and Superior are systematically being sampled on an annual basis to obtain information on areas where contaminants approach or exceed FDA guidelines for consumer protection. The project, developed by the State agencies in cooperation with the U.S. Food and Drug Administration and the Bureau of Sport Fisheries and Wildlife Great Lakes Laboratory, will establish patterns of residues of mercury, PCB's, DDT and dieldrin in Great Lakes fish. Table 8 shows the concentrations of PCB's detected in fish from Lake Michigan during the first year of this study. PCB's in Salmonids (lake trout, steelhead, coho salmon, and chinook salmon) and chubs were shown to exceed the FDA guideline of 5.0 ppm while concentrations in other species did not exceed this guideline. Sampling will be continued on an annual basis.

One area in which we have very little information so far is the potential for loss of PCB's from electrical transformers (one of the two remaining uses) through leakage, servicing, and replacement of worn-out or damaged units. We hear rumors that many of the small transformer maintenance companies, apparently unaware of the potential hazards of PCB's, are dumping PCB-based transformer fluids down the nearest drain or giving them to waste oil haulers rather than returning them for incineration. We intend to make a questionnaire survey followed up by an educational type letter with guidelines for safe disposal.

In summary, we think we have made considerable progress in the past 2 years toward getting rid of the PCB problem. On the other hand, while we have some indications of environmental reductions, we are afraid the contamination problems are not going to disappear as rapidly as we would like because of the slow transition to substitute products and the tremendous capacity for biological communities to magnify this type of persistent compound.

John L. Hesse
Aquatic Biologist
Water Quality Appraisal Section
Bureau of Water Management
Department of Natural Resources

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Basin	River	PCB's (ppb as 1254)	Range (ppb as 1254)
igan	St. Joseph	0.013	<0.010-0.039
	Kalamazoo	0.065	0.019-0.097
	Grand	0.041	0.011-0.080
	Muskegon	0.010	<0.010-0.037
	Manistee	0.014	<0.010-0.039
	Boardman	0.017	<0.010-0.044
	Elk	0.012	<0.010-0.039
n	Saginaw	1.100	0.450-2.900
	Cass[1]	0.014	<0.010-0.048
	Flint[1]	0.078	0.010-0.150
	Shiawassee[1]	0.029	<0.010-0.073
	Tittabawassee[1]	0.140	<0.022-0.230
	Au Sable	<0.010	<0.010-0.010
	Thunder Bay	0.023	<0.010-0.037
	Cheboygan	0.032	<0.010-0.053
lair	Clinton	0.150	<0.039-0.430
	Black	0.043	<0.010-0.110
	St. Clair	0.010	<0.010-0.029
	Raisin	0.210	<0.068-0.500
	Huron	0.012	<0.010-0.039
	Rouge[2]	0.470	0.058-1.500
	Detroit	0.020	<0.010-0.053

utary to Saginaw River
iary to Detroit River downstream from Detroit River sampling station

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Table 4. Concentrations of poly-chlorinated biphenyls (PCB's) in fish from Saginaw River, December 7, 1971. (ppm; wet weight).

Species	Location	Length	Percent fat	PCB's based upon 1242 standard
Perch	Karn-Weadock Discharge Channel	9.0	1.3	16.3
Carp	" " " "	21.0	0.9	8.8
Catfish	" " " "	8.0	7.0	37.1
Catfish	" " " "	7.5	4.9	47.9
Carp	U.S. Coast Guard Station	23.0	---	48.0
Carp	" " " "	24.0	10.5	20.4
Carp	" " " "	20.0	6.5	15.5
Carp	" " " "	24.0	5.9	45.8
Carp	" " " "	21.0	4.6	30.2
Pike	" " " "	27.0	1.6	16.6
Pike	" " " "	23.0	1.1	6.9
Gizzard Shad	" " " "	14.0	17.5	165.3
Gizzard Shad*	" " " "	6.0	15.3	32.5
Gizzard Shad*	" " " "	4.5	15.0	161.9
Gizzard Shad*	" " " "	5.0	17.0	77.0
Gizzard Shad*	Zilwaukee Bridge	4.5	15.7	24.1
Gizzard Shad*	" "	5.0	9.6	52.0
Gizzard Shad*	" "	5.0	8.7	10.4

* Concentration based upon analysis of whole fish. All others based upon edible portion only.

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Table 3. PCB Concentrations in Michigan Tributaries to the Great Lakes, May - June, 1973. Concentrations in parts per billion.

Lake Basin	River	Collection Date	PCB's as Aroclor 1254
Michigan	St. Joseph	5-11-73	≤ 0.010
	Kalamazoo	5-11-73	0.040
	Grand	5-11-73	0.033
	Muskegon	5-11-73	≤ 0.010
	Manistee	5-11-73	0.037
	Boardman	5-17-73	0.018
	Elk	5-17-73	≤ 0.010
Huron	Saginaw	5-24-73	0.210*
	Cass	5-24-73	≤ 0.010
	Flint	5-24-73	≤ 0.010
	Shiawassee	5-24-73	≤ 0.010
	Tittabawassee	5-24-73	≤ 0.010
	AuSable	5-17-73	0.013
	Thunder Bay	5-17-73	≤ 0.010
	Cheboygan	5-17-73	≤ 0.010
St. Clair	Clinton	6-8-73	0.200*
	Black	6-8-73	0.052
	St. Clair	6-8-73	≤ 0.010
Erie	Raisin	6-8-73	≤ 0.010
	Huron	6-8-73	≤ 0.010
	Rouge	6-8-73	0.460*
	Detroit	6-8-73	≤ 0.010

*Aroclor 1242

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of Municipal Wastewater Treatment Plants throughout Michigan 1971-1972. Unless specified, all samples are 8 hr. composites.

CITY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
Adrian	3-30-72	1.80	4.60
	6-13-72	14.00	
	6-14-72	6.90	
	9-6-72	0.41	
Albion	3-28-72	0.44	0.44
Ann Arbor	10-14-71	0.14	0.12
	3-30-72	<0.10	
Battle Creek	10-5-71	0.39	0.39
	3-28-72	0.16	
	2-21-72	0.92	
	6-6-72	0.28	
	6-7-72	0.21	
Bay City	11-4-71	340.00	120.00
	11-22-71	210.00	
	11-23-71	60.00	
	3-2-72[a]	200.00	
	4-4-72	19.00	
	6-13-72	11.00	
	6-14-72	25.00	
	9-14-72	5.70*	
Grand Haven -	10-28-71	0.99	0.65
St. Joseph	4-4-72	0.31	
Ishpeming	10-5-71	0.38	0.38
Marquette	7-20-72	0.61	0.61
Mascantine	4-4-71	0.85	0.85
Detroit	10-14-71	2.20	1.95
	12-20-72[c]	3.00	
	1-20-72	0.92	
	3-9-72	2.40	
	4-17-72[b]	1.80	
	6-1-72	0.88	
	10-19-72	2.50**	
Dexter	10-14-71	<0.10	0.10

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CITY	DATE	PCB's Aroclor 1254 (ppb)	Mean Conc. (ppb)
. Lansing	11-15-71	0.69	0.51
	4-3-71	0.35	
scanaba	12-16-71	0.29	0.29
sscoxville	11-4-71	0.21	0.24
	3-31-72	0.28	
lint	10-5-71	1.30	0.68
	3-31-72	0.92	
	6-7-72	0.47	
	6-8-72	0.30	
	10-5-72	< 0.10	
lushing	10-5-72	0.52	0.52
ladstone	7-21-72	0.19	0.19
rand Haven	4-4-72	< 0.50	< 0.50
rand Rapids	11-15-71	0.37	0.52
	3-30-72	0.68	
olland	10-20-71	0.79	0.60
	3-29-72	0.42	
oughton- ncock	3-21-72	< 0.10	0.10
t. Mc ingsford	3-21-72	0.55	0.87
	4-4-72	1.20	
ronwood	3-20-72	0.16	0.16
ckson	11-16-71	<0.10	<0.10
	2-21-72	<0.10	
	3-28-72	<0.10	
alamazoo	10-5-71	1.30	0.66
	3-28-72	0.83	
	6-6-72	0.48	
	6-7-72	0.53	
	12-6-72	0.19	
Anse	4-21-72	<0.10	<0.10
nsing	10-7-71	0.23	0.18
	4-4-72	0.13	

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ITY	DATE	PCB/s Aroclor 1254 (ppb)	Mean Conc. (ppb)
anistique	12-15-72	<0.20	<0.20
arquette	12-14-71	0.35	0.35
arshall	3-28-72	<0.10	<0.10
enominee	12-15-71	0.35	0.35
idland	2-2-72	0.29	0.23
	3-31-72	0.40	
	4-14-72	0.13	
	10-2-72[d]	0.13	
ilford	10-14-71	<0.10	<0.10
onroe	11-15-71	0.60	0.46
	3-30-72	0.33	
t. Clemens	11-15-71	1.40	5.21
	3-30-72	2.90	
	6-7-72[c]	4.50	
	6-8-72[c]	3.10	
	7-26-72	9.40	
	8-2-72	10.00	
t. Pleasant	3-31-72	<0.10	<0.10
uskegon	11-15-71[c]	0.28	0.28
uskegon Heights	11-15-71[c]	0.37	0.37
iles	4-4-72	0.68	0.68
orway	4-5-72	0.40	0.40
ntonagon	4-21-72	<0.10	<0.10
osso	9-14-72	<0.10	<0.10
rchment	4-20-72	<0.10	<0.10
ntiac (Auburn Rd.)	11-17-71	<0.10	0.35
	3-30-72	0.61	
ntiac (E. Blvd.)	11-17-71	0.20	0.45
	3-30-72	1.30	
	6-6-72	0.15	
	6-7-72	0.16	
rtage	11-15-71[d]	1.90	1.90

TY	DATE	PCB's as Aroclor 1254 (ppb)	Mean Conc. (ppb)
rt Huron	11-15-71	0.28	0.40
	3-30-72	0.52	
ginaw	10-6-71	1.10	1.80
	3-31-72	3.80	
	6-7-72	2.00	
	6-8-72	1.50	
	10-4-72[d]	0.74	
. Ignace	12-15-72	<0.20	<0.20
uth Haven	4-4-72	<0.10	<0.10
rtz Creek	10-5-72	<0.10	<0.10
ree Rivers	4-4-72	<0.30	<0.30
enton	11-16-71	0.14	0.53
	3-30-72	1.10	
	6-6-72	0.47	
	6-7-72	0.91[e]	
rren	11-15-71	0.16	0.13
	3-30-72	0.10	
yne County yandotte)	11-16-71	0.64	0.40
	3-30-72	0.17	
ite Pine	4-21-72	0.2	0.20
oming	11-30-72[c]	0.44	0.49
	3-30-72	0.55	
ilanti	11-16-71	0.22	0.21
	4-2-72	0.21	
ilanti Twp #1	11-16-71	0.12	0.11
	4-2-72	<0.10	
ilanti Twp #2	11-16-71	0.19	0.17
	4-2-72	0.16	

roclor 1242 Standard
roclor 1242 and 1254 in 1:1 ratio

hr [b]10 hr [c]24 hr [d]Grab [e]hexane lost · GRAND MEAN 2.55

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Spring, 1973. Concentrations in parts per billion dry weight.

ITY	DATE	PCB's		
		1242	1254	1242:1254
Arian	3/7			0.26
lbion	2/22		0.34	
n Arbor	3/1		0.25	
y City	3/1	3.20		
ttle Creek	2/28		<0.10	
nton Harbor- St. Joseph	2/28		0.20	
ighton	3/1			0.33
dillac	3/28		0.53	
rlotte	5/1		0.34	
stentine	2/28		0.46	
troit	2/28	2.15		
xter	3/1		0.23	
st Lansing	5/2		0.18	
canaba	3/28			0.28
ssexville	3/1		0.10	
int	2/22		<0.10	
adstone	3/28		0.44	
and Haven	2/21		<0.10	
and Rapids	2/21		1.05	
olland	2/21		<0.10	
[illegible]				
laucock	3/27		0.18	
[illegible]				
ingsford	3/28		0.69	
	3/27			0.29
ckson	2/22		<0.1	
lamazoo	2/29			1.12
'Anse	3/27			0.31
nsing	4/18		0.22	
nistique	3/28		0.63	
rquette	3/27		0.29	
rshall	2/22		0.15	
ominee	2/28		0.57	
idland	3/1		<0.10	
ilford	3/8			2.20
nroe	5/4		<0.10	
. Clemens	3/8			2.90
. Pleasant	3/28		0.29	
skegon	2/28		0.88	
kegon Heights	2/28		0.18	
es	2/20		0.48	
nway	3/28		<0.10	
sco	2/21		0.12	
tiac (Auburn)	3/12			0.60
tiac (E. Blvd.)	3/12			0.54
t Huron	3/8			1.80
inaw	3/1			0.77
ult Ste. Marie	3/28		0.73	

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CITY	DATE	PCB's		
		1242	1254	1242:1254
St. Ignace	3/28		0.31	
Three Rivers	2/21		<0.10	
Traverse City	3/7		<0.10	
Trenton	2/28		<0.10	
Warren	2/27		<0.10	
Wayne County	2/28		0.40	
Wyoming	2/21		0.22	
Ypsilanti	2/28			0.31
Ypsilanti Twp #1	3/1		<0.10	
Ypsilanti Twp #2	3/1		<0.10	

Concentrations based on best fit of 3 standards: Aroclor 1242, Aroclor 1254, or a mixture of Aroclor 1242 and 1254 in a 1:1 ratio.

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Table 6. Concentrations of PCB's in the sludge from fifty-seven municipal wastewater treatment plants in Michigan, Spring 1973. Concentrations in parts per million, dry weight.

City	Date	PCB's* 1242	1254	1242:1254
Adrian	3/ 7			24.0
Albion	2/22		1.5	
Ann Arbor	3/1		1.1	
Bay City	3/1	352.0		
Battle Creek	2/28		2.8	
Benton Harbor-St. Joseph	2/28		13.8	
Brighton	3/1		<0.1	
Cadillac	3/28		<0.1	
Charlotte	5/1		6.8	
Constantine	2/28		2.1	
Detroit	2/28	32.1		
Dexter	3/1		3.2	
E. Lansing	5/2		4.6	
Escanaba	3/28		5.9	
Essexville	3/1		3.9	
Flint	2/22		6.3	
Gladstone	3/28		4.1	
Grand Haven	2/21		4.1	
Grand Rapids	2/21		11.8	
Holland	2/21		0.8	
Howell	4/26		15.0	
Houghton Hancock	3/27		5.5	

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City	Date	PCB's 1242	1254	1242:1254
Iron Mountain - Kingsford	3/28		9.5	
Ironwood	3/27		5.2	
Jackson	2/22		3.0	
Kalamazoo	2/29	23.3		
L'Anse	3/27		4.4	
Lansing	4/18		5.3	
Manistique	3/28		1.5	
Marquette	3/27		2.8	
Marshall	2/22		3.9	
Menominee	2/28		4.2	
Midland	3/1		2.9	
Milford	3/8			50.5
Monroe	5/4		3.3	
Mt. Clemens	3/8	175.0		
Mt. Pleasant	3/28		6.5	
Muskegon	2/28		12.7	
Muskegon Heights	2/28		11.0	
Niles	2/20		7.8	
Norway	3/28		<0.1	
Owosso	2/21		2.0	
Pontiac (Auburn)	3/12			12.1
Pontiac (E. Blvd.)	3/12			9.2
Port Huron	3/8			9.2

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Table 7. Polychlorinated biphenyls (PCB's) in composite water samples from the Saginaw River at Bay Harbor Marina, March 1971 - May 1973.

Collection Date	Concentration in parts per billion
3-9-71	0.450
6-10-71	0.560
8-27-71	2.900
10-26-71	1.100
6-8-72	0.640
10-13-72	0.360
10-29-72	<0.020
10-30-72	<0.020
11-1-72	0.091
11-2-72	0.031
11-4-72	<0.020
11-6-72	0.022
1-26-73	<0.100
5-24-73	0.210

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le 8. Concentrations of polychlorinated biphenyls (PCB's) found in fish species taken from Michigan waters of Lake Michigan during 1972*.

cies	PCB's by District**in ppm (sample size in parenthesis) MM3	MM4	MM5	MM6	MM7	MM8	Total # Fish Sampled	Mean Concentrati
·ife	1.7 (3)			2.3 (1)	2.7 (6)	2.7 (6)	16	2.4 ± 0.6
)					3.9 (6)		6	3.9 ± 2.0
)				3.2 (2)	8.5 (8)	6.5 (9)	19	7.0 ± 4.2
·minee				0.8 (1)	1.2 (2)		3	1.1
h				0.5 (1)	0.4 (5)	0.5 (11)	17	0.4 ± 0.4
Salmon			11.2 (3)				3	11.2
ook almon				12.4 (10)			10	12.4 ± 5.0
ers	0.8 (6)			0.7 (2)	1.5 (3)	1.1 (6)	17	1.0 ± 0.7
Head			6.0 (2)				2	6.0
Trout	11.1 (3)	6.4 (3)		3.2 (2)	5.7 (6)	9.2 (6)	20	7.4 ± 4.0
fish		0.6 (3)		0.8 (2)	1.1 (1)		6	0.7 ± 0.3

* From Michigan's Great Lakes Environmental Contaminant Survey, 1972.
nes of Lake Michigan within Michigan Boundaries
3 - Northern Basin
4 - Grand Traverse Bay
5 & MM6 - Central Basin
7 & MM8 - Southern Basin

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