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Environmental Occurrence, Abundance, and Potential Toxicity of Polychlorinated Biphenyl Congeners: Considerations for a Congener-Specific Analysis

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Polychlorinated biphenyls (PCBs) as environmental contaminants often cannot be adequately described by reference to Aroclors or to total PCBs. Although there are 209 possible PCB configurations (congeners), perhaps half that number account for nearly all of the environmental contamination attributable to PCBs. Still fewer congeners are both prevalent and either demonstrably or potentially toxic. If potential toxicity, environmental prevalence, and relative abundance in animal tissues are used as criteria, the number of environmentally threatening PCB congeners reduces to about thirty-six. Twenty-five of these account for 50 to 75% of total PCBs in tissue samples of fish, invertebrates, birds, and mammals.

A few PCB congeners that are sterically similar to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) are directly toxic. Other PCB congeners, as well as those that are directly toxic, may also be involved in toxicity indirectly by stimulating the production of (inducing) bioactivating enzyme systems. The most consequential of these have the ability to induce aryl hydrocarbon metabolizing mixed-function oxidases (MFOs). A result can be an increased capacity for bioactivation of otherwise nontoxic foreign compounds such as certain polynuclear aromatic hydrocarbons (PAH) to cytotoxic or genotoxic metabolites. The effectiveness of specific PCB congeners as inducers of different types of cytochrome P-450-dependent MFO systems is determined by their stereochemistry. Although MFO induction is not a proximate cause, it is a strong correlate of certain kinds of toxicities. Structural patterns can thus be used to discriminate among PCB congeners on the basis of toxic *potential*, if not entirely on toxicity *per se*. Congeners that demonstrate 3-methylcholanthrene-type (3-MC-type) and mixed-type MFO induction have the greatest toxic potential. These congeners most closely resemble 2,3,7,8-TCDD in their structures and in their toxic effects. The larger group of phenobarbital-type (PB-type) inducers have considerably less potential for contributing to toxic effects. Weak inducers and noninducing congeners have the least potential for toxicity.

Using the rationale described in this paper, we assigned the most environmentally threatening PCB congeners to four groups. Congeners assigned to Group 1 are considered most likely to contribute to adverse biological effects attributable to PCBs in an environmental sample. Group 1A contains the three most potent (pure 3-MC-type inducer) congeners, IUPAC numbers 77, 126, and 169. Six congeners, numbers 105, 118, 128, 138, 156, and 170, are assigned to Group 1B. These congeners are mixed-type inducers that have been reported frequently in environmental samples. Group 2 congeners are PB-type inducers that are also prevalent in the environment; these include numbers 87, 99, 101, 153, 180, 183, and 194. Group 3 congeners, numbers 18, 44, 49, 52, 70, 74, 151, 177, 187, and 201, are weak or noninducers, but they occur frequently in the environment or in high concentrations in animal tissues relative to other PCB congeners, and so may be of concern. Of possible importance are congeners 37, 81, 114, 119, 123, 157, 158, 167, 168, and 189. These are mixed-type inducers that have been reported infrequently in biota and in very low tissue concentrations and are assigned to Group 4.

Introduction

Polychlorinated biphenyls (PCBs) are among the neutral organic chemicals most commonly of concern as environmental contaminants. PCBs are widespread, persistent, and have the potential for harmful biological effects. Current practice in regulatory evaluation of PCBs in environmental samples involves quantitation as total PCBs or as the total based on Aroclor equivalents (*1–3*). Quantitation of environmental samples as equivalents of technical PCB formulations, such as Aroclors, can result in substantial qualitative and quantitative errors (*4–5*). When subjected to processes of degradation and mixing in environmental compartments, the identity of Aroclor

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mixtures is altered (*6*). The correlation between the chromatogram of an Aroclor standard and that of PCB mixtures from an environmental sample is variable (*7–11*), and conventional quantitation methods permit considerable subjectivity on the part of the analyst (*12–14*). Additionally, reporting concentration data as total PCBs provides no information about the potential biological significance of the particular mixture of congeners in a sample and may be misleading. For example, it was noted that monochlorobiphenyls constituted as much as one-third of the total PCBs in samples of water, sediment, clams, and fish in an investigation involving contaminated sediments from the upper Hudson River. Such samples, if reported as total PCBs, would be considered potentially more toxic that warranted (*15*).

The most bioaccumulating PCB congeners have five to seven chlorine atoms per molecule. These moderately chlorinated isomer groups (penta-, hexa-, and heptachlorobiphenyls) contain 112 of the 209 possible PCB configurations. They were synthesized in high proportions in many Aroclor formulations and are likely to be prevalent in environmental matrices (*8,16*). The moderately chlorinated isomer groups also contain most of the mixed-function oxidase (MFO)-inducing congeners. Two of the three pure 3-MC-type inducers and all but two of the mixed-type inducers are penta-, hexa-, or heptachlorobiphenyls (*17–24*). The more highly chlorinated congeners are generally less available to organisms both because they are more tightly bound with soils and sediments and because they usually are present in lower quantities in the environment. Congeners with less chlorination are more readily metabolized and eliminated and so do not tend to bioaccumulate as highly (*17,18,25*).

Chemical synthesis of all 209 PCB congeners, as well as separation and quantitation as discrete peaks from mixtures, although difficult, is possible using modern capillary column gas chromatographic methods (*26,27*). However, analysis for all of the congeners is not necessary for routine regulatory evaluations because many PCB congeners have never been reported in environmental samples, are not toxic, or have low bioavailability (*15,16,28*). An essential step in the development of a regulatory congener-specific analytical protocol is identification of the appropriate PCB congeners for inclusion in an analytical calibration standard. The purpose of this paper is to review current understanding of PCB environmental occurrence, potential toxicity, and prevalence as a rationale for determining the appropriateness of specific PCB congeners for inclusion in an analytical standard intended for application to environmental matrices.

Numbering of congeners in this paper follows the convention proposed by Ballschmiter and Zell (*29*) and later adopted by the International Union of Pure and Applied Chemists (IUPAC). IUPAC number, structure, and isomer group are given for each congener in Appendix A. The system of numbering and the nomenclature (*ortho-, meta-, para-*) convention for the biphenyl nucleus, along with the numbering of dioxin and dibenzofuran, are shown in Figure 1.

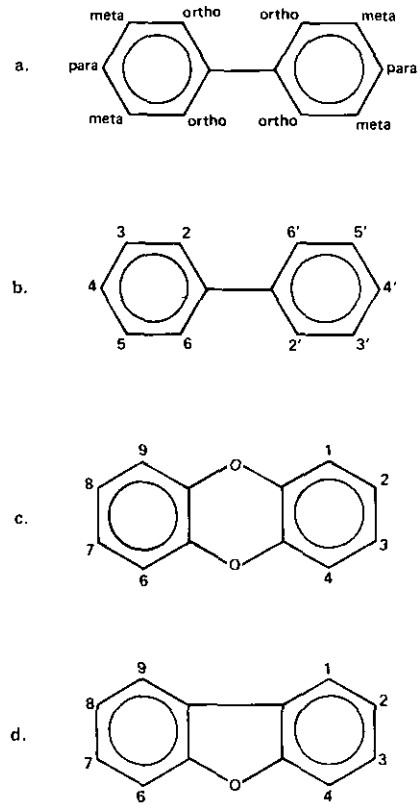

FIGURE 1. Structure and positional nomenclature (*a*) and numbering (*b*) for biphenyl. Structure and numbering for dibenzo-*p*-dioxin (*c*) and dibenzofuran (*d*).

Toxicity, Enzyme Induction, and Structural Patterns of PCBs

Toxicity to Aquatic Biota

PCBs are not acutely toxic to aquatic biota in the natural environment. The U.S. Environmental Protection Agency water quality criteria document for PCBs (*3*) noted that problems possibly could exist with the validity of acute toxicity tests because of the low solubility of PCBs in water and because the solubilities of PCBs are less than their acute toxicities. Experiments in which neonate daphnids and fathead minnow fry were exposed to saturated aqueous solutions of pure individual PCB congeners for 48 to 96 hr resulted in no mortalities that were attributable to PCB toxicity (*30*). The solutions were produced using a generator column and did not employ a carrier, such as acetone, a practice used in earlier work that may have resulted in unrealistically high acute toxicity results for PCBs (*31–33*).

These results are in agreement with the work of other researchers (*34*) who found that water solubility is the primary determinant of acute toxicity of a series of hydrocarbons and chlorohydrocarbons to *Daphnia magna* and *Artemia salina*. Abernethy et al. (*34*) also noted that since there is a trend for larger molecules to be less soluble in octanol, they also may be less soluble in the lipids of organisms. Such large volume molecules (e.g., the PCBs)

may partition less easily into sites of toxic action within cells. Kinetic factors also influence acute toxicity, and larger molecules may take longer to establish concentrations necessary to produce toxic manifestations because of their lower diffusivity in water and lipid phases.

Toxic effects of aquatic environmental PCB contamination appear most likely to be sublethal and chronic. Physiological functions that are controlled by steroid hormones may be altered by exposure of organisms to PCBs (*35–37*). Growth, molting, and reproduction are primary functions that have been shown to be affected by exposure of aquatic organisms to PCBs in numerous laboratory investigations. The ability of organisms to eliminate foreign organic compounds or endogenous waste products also may be affected. Steroid biosynthesis and the degradation and biotransformation of foreign compounds are metabolic activities in both fish and higher vertebrates that are strongly influenced by terminal oxidase activities of the microsomal cytochrome P-450 systems (referred to also as mixed-function oxidase or MFO systems). Some, although not all, PCB congeners are MFO inducers in fish, mammals, and birds, and to a lesser extent in aquatic invertebrates.

Inhibited growth was reported (*38*) in juvenile salmon exposed to a tetra- (number 77) and two hexachlorobiphenyl congeners (numbers 153 and 155). Growth of minnows fed food contaminated with a technical PCB formulation, Clophen A50, was stimulated at high PCB doses (*39*). However, other investigators (*40*) reported significantly impaired growth and bone development in brook trout fry at 48 days after hatching. Although these and other referenced exposures were conducted at PCB concentrations substantially above those likely to be encountered in the environment, Aroclor 1254 residues in the brook trout from the lowest exposure concentrations were within the range found in some fish from feral populations. The authors (*40*) speculated that the observed adverse effect on bone development was a realistic indication of a potential toxic impact of Aroclor 1254 in the case of brook trout, and perhaps other fish species. In recent experiments, reproduction was significantly impaired in fathead minnows induced to spawn after exposure to PCB-contaminated natural sediments for 7 weeks. Exposure to pure PCB congeners selected for expected toxic potential did not result in any impairment of reproduction (T. M. Dillon, personal communication).

Molting of fiddler crabs has been reported to be severely impaired in laboratory exposures to Aroclor 1242 and to octachlorodibenzofuran (*41*). Juvenile crabs, *Cancer magister*, exposed to suspensions of a harbor sediment containing PCBs, petroleum hydrocarbons, metals, and other contaminants, were deformed and died during molting (*42*). It has been observed that ovarian development and the molt cycle are closely linked in crustaceans (*37*). The molting agent, ecdysone, is a steroidal hormone related structurally to androgens and estrogens. A contaminant that causes a dysfunction in steroid biosynthesis and/or biotransformation and degradation could presumably result in impaired molting and reproductive success of some aquatic organisms.

Marine polychaetes, *Nereis virens*, that were exposed to the procarcinogenic aromatic hydrocarbon benzo[a]pyrene and to Aroclor 1254 were found to have significantly elevated MFO activity (*36*). Feral *Nereis virens* were then collected from clean reference and from oil-contaminated sites. The worms from the oil-contaminated sites had MFO activities approximately six times greater than those from the reference site and had only one-sixth the body weight of the reference site worms. Other work (*43,44*) correlated elevated MFO activities and reproductive failure in flatfish with PCB and oil ingestion, as well as with elevated PCB concentration in sediment at the collection site.

A major difficulty in interpreting the relevance of these findings to PCB contamination in the environment is a lack of clear causal relationships. Aquatic organisms in natural circumstances are almost always exposed to a variety of interacting contaminants. The interactions may be additive, synergistic, or antagonistic. In addition, the data regarding the toxicity of individual PCB congeners to aquatic biota are scant and often contradictory. However, the evidence for PCB congener-specific toxicity to higher vertebrates is much better developed, and it is now known that a large group of halogenated hydrocarbons that are approximately isosteric (including certain of the PCBs) elicit similar biochemical and toxic effects and appear to act by the same or similar mechanisms (*45–50*). It is beyond the scope of this report to review the large body of literature reporting research in mammalian and avian toxicology of halogenated aromatic compounds, including the PCBs [for a comprehensive review, see Kimbrough (*51*)]. However, the stereospecificity required for certain types of MFO induction and that required for many toxic effects is the same, and although MFO induction is not a proximate cause, it is a strong correlate of some kinds of toxicities (*52–55*). Contamination of fish and shellfish with PCBs is a concern to the health of human consumers as well as for the protection of avian and terrestrial wildlife. Therefore, the approach taken in this paper relies on the structural specificity of PCB congeners for microsomal enzyme induction as the best characterized indicator of potential toxicity.

Mixed-Function Oxidase Induction by PCBs

The group of microsomal cytochrome P-450-dependent enzyme systems that catalyze oxidative biotransformations of aromatic ring-containing compounds fall in the category of mixed-function oxidases. Different types of cytochrome P-450 systems are frequently characterized by reference to model chemicals that stimulate (induce) or inhibit the production of these enzymes. The MFOs that are induced by PCBs are characterized as being phenobarbital-type (PB-type), 3-methylcholanthrene-type (3-MC-type), or possessing catalyzing properties of both (mixed-type). The different types of inducers are specific for different substrates and have different regioselectivities for catalyzing the insertion of oxygen in the formation of reactive intermediates (*56*). Bromobenzenes, for ex-

ample, were catalyzed by PB-induced rabbits to form 3,4-epoxides, whereas 3-MC-induction resulted in formation of 2,3-epoxides (*57*). The difference can be consequential in terms of toxicity. In the case of bromobenzenes, the 3,4-epoxide is hepatotoxic and the 2,3-epoxide is not. Dichlorobiphenyls were also metabolized differently by PB-induced animals and by animals induced with β-naphthoflavone (BNF), a chemical having inducing properties in common with 3-methylcholanthrene. With two *ortho*-chlorine substituents, the dichlorobiphenyls were metabolized predominantly by PB-inducible MFOs, and with no *ortho*-chlorines, BNF was the effective inducer of metabolizing enzymes (*58*).

The PB-inducible MFOs catalyze insertion of oxygen into conformationally nonhindered sites of globular or noncoplanar lipophilic molecules, facilitating their conjugation and removal (*59*). Ordinarily, reactions catalyzed by PB-inducible enzymes in Phase I detoxication go on to conjugation with endogenous substrates such as glutathione, glutamic acid, or sulfate in Phase II (*60*). Conjugation generally increases the water solubility of lipophilic molecules, making them more easily excreted. In some instances, as in the case of bromobenzene, PB-inducible MFOs may have a role in the bioactivation of toxic intermediates. The 3-MC-inducible MFOs function to insert oxygen into conformationally hindered sites of planar molecules such as certain polynuclear aromatic hydrocarbons (PAHs) (*59*). The results of these reactions may be formation of carcinogenic, mutagenic, or teratogenic biotransformation products from otherwise nontoxic parent compounds. The best characterized example of this is the bioactivation of benzo[a]pyrene (BaP) to the ultimate carcinogens, the BaP-7,8-dio1-9,10-expoxides (*61*). Conformational hindrance of the oxygenated molecule provides stability and tends to inhibit conjugation and detoxication that usually occurs readily in the case of PB-inducible enzymic action. Since reactive epoxides are formed as transition products by both PB- and 3-MC-inducible enzymes, both types have the potential for producing toxicity through bioactivation. In the case of bromobenzene, toxicity was enhanced in PB-induced animals (*58,62,63*); however, the potential for contributing to toxicity through bioactivation is considered to be much greater with the 3-MC-inducible enzymic reactions.

The MFOs of fish, and apparently of aquatic invertebrates, are qualitatively similar to the 3-MC-inducible MFOs of vertebrates (*37,59,64,65*). Phenobarbital-type induction has been reported in mummichog, rainbow trout, and carp in a few investigations; however, most studies have not demonstrated PB-type MFO activity in fish (*66*). Quantitatively, the detoxifying capability of fish appears to be about one-tenth that of mammals (*37*). The enzymes aryl hydrocarbon hydroxylase (AHH) and ethoxyresorufin *O*-deethylase (EROD) are characteristic in fish as well as in 3-MC-induced mammals.

Molecular Structure and PCB Congener Toxicity

Potency and specificity for MFO induction (and correlatively, for potential toxicity) of individual PCB congeners

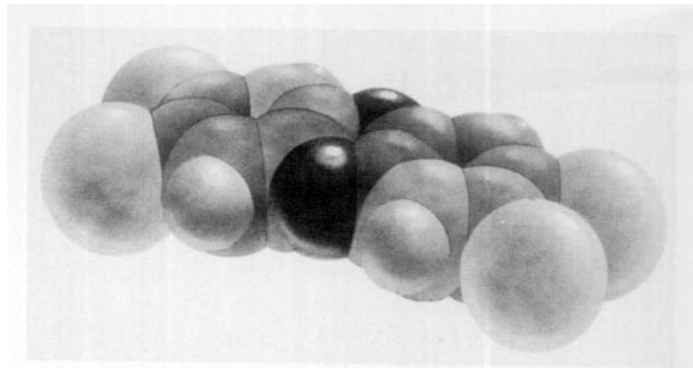

FIGURE 2. Molecular model of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. Dark spheres are oxygen atoms. The four large light spheres at the ends of the molecule are chlorine atoms.

can be directly related to how closely they approach the molecular spatial configuration and distribution of forces, i.e., are isosteres, of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). The dioxin, 2,3,7,8-TCDD (Fig. 2), is generally considered the most potent synthetic environmental toxicant and is regarded as a standard for comparison for other organic toxicants that are more or less isoteric, such as some of the PCBs (*48,50,52,55*). Dioxins are chlorinated aromatic molecules that form a planar volume in the form of a box or rectangle occupying about 3 by 10 Å (*67*). The cytosolic receptor that binds 2,3,7,8-TCDD is a soluble protein produced by the *Ah* (aryl hydrocarbon) gene locus. Binding of 2,3,7,8-TCDD or its isosteres to the *Ah* receptor is facilitated by coplanarity of the phenyl rings within the 3 by 10 Å dimensions. Other factors such as polarizability of the lateral chlorines may be important in determining the strength of binding to the receptor (*19*). Translocation of the inducer-receptor complex to the nuclear *Ah* locus is thought to initiate the synthesis of AHH, EROD, and related enzymes that may be involved in either biotransformation, conjugation and removal, or the bioactivation of certain planar lipophilic foreign compounds to toxic intermediates (*46,47,49*).

The most toxicologically active PCB congeners are those having chlorine substitution at the *para* (4 and 4′) and at least two *meta* (3,3′5, and 5′) positions on the biphenyl nucleus, but no *ortho* (2,2′6, and 6′) substitutions (Fig. 1*a,b*) (*24*). Because the phenyl rings of a biphenyl nucleus are linked by a single carbon:carbon bond, the two rings have relatively unconstrained rotational freedom. Unlike dioxins (Fig. 1*c*) or dibenzofurans (Fig. 1*d*), the phenyl rings of a PCB are not rigidly bound in the same plane. X-ray crystallographic analyses indicate that the preferred conformation for all PCBs, including those without *ortho*-substituents, is noncoplanar (*67*). The proportion of molecules of a particular congener assuming a coplanar configuration becomes increasingly small as the energetic cost of conforming increases (*67*). Chlorines are very bulky atoms, and the substitution of a chlorine at certain positions on the biphenyl nucleus inflicts constraints on rotational freedom. The greatest effect is exerted by substitution of at least two opposing *ortho*-substituted chlorines on opposite rings (*58,68*). Increasing the number of chlorine atoms at the *ortho* points increases steric hindrance to rotation (Fig. 3).

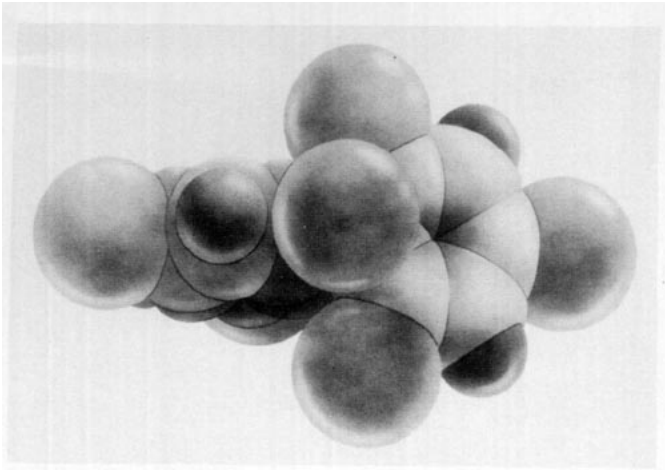

FIGURE 3. Model of 2,2',4,4',6,6'-hexachlorobiphenyl (congener number 155) illustrating steric hindrance to rotation of the rings imposed by substitution of the maximum possible number of chlorine atoms (four) at the *ortho* positions of the molecule. Rings are shown rotated at the angle of preferred orientation, 87.3°.

Pure 3-Methylcholanthrene-type Inducers

The PCB congeners that have no *ortho* substitutions can assume a coplanar configuration (Fig. 4). Because potential toxicity is enhanced by coplanarity, this rule limits the number of PCB congeners that may be expected to be toxicologically most active to four. These congeners are numbers 77, 81, 126, and 169 (Appendix A). With the exception of number 81, the non*ortho*-coplanar congeners are potent inducers of AHH and EROD in *in vitro* rat hepatoma cell preparations. The *in vitro* induction of AHH and EROD is correlated with *in vivo* demonstrations of mammalian toxicity such as thymic atrophy and inhibition of body weight gain (*52–55,69*).

Congeners 77, 126, and 169 are pure 3-MC-type inducers; congener 81 demonstrates mixed-type induction. Tanabe et al. (*70*) reported the presence of congeners 77, 126 and 169 in tissue samples from a wide range of organisms including marine mammals and humans. Residues of congeners 77, 126 and 169 were present in sufficiently high concentration to conclude that these non*ortho*-coplanar PCBs, and particularly number 126, pose a greater threat to humans and wildlife than does 2,3,7,8-TCDD itself.

The conclusion of Tanabe et al. (*70*) was made on the basis of a summation of toxic equivalents, i.e., the product of molar concentration and potency for AHH and EROD induction of chemicals relative to 2,3,7,8-TCDD in *in vitro* rat hepatoma cell cultures (*52–55*). Whether this approach will prove valid remains to be seen. Some results of recent investigations (*71,72*) have indicated that the PCB mixture Aroclor 1254 is a dioxin antagonist in rat hepatoma H-4-II E cells, *in vitro*, and in C57BL/6J mice, *in vivo*, if administered at noneffective (below toxic threshold) doses. The mechanism is thought to be competitive inhibition in which the more abundant and sterically similar but less effective PCB congener molecules outcompete 2,3,7,8-TCDD for the same cytosolic receptor sites. The three non*ortho*-coplanar PCB congeners are close isosteres of 2,3,7,8-TCDD, and appear to act by the same mechanism. If competitive inhibition by less effective PCB congeners in a mixture reduces the enzyme-inducing effectiveness and the toxicity of congeners such as numbers 77, 126, and 169, then summation of toxic equivalents cannot be a viable approach for estimating the toxic significance of these chemicals in the environment. In reports previously cited (*71,72*), it was noted that exposure to nontoxic levels of PCBs in the environment may protect humans to some extent from concomitant exposure to much more toxic dioxins and dibenzofurans. Implications regarding other environmental effects are substantial: if this instance of competitive inhibition is a generally operant mechanism in biota, it could provide insight into the ability of most adult organisms, including fish and shellfish, to carry seemingly large body burdens of dioxins, furans, and PCBs without apparent effect.

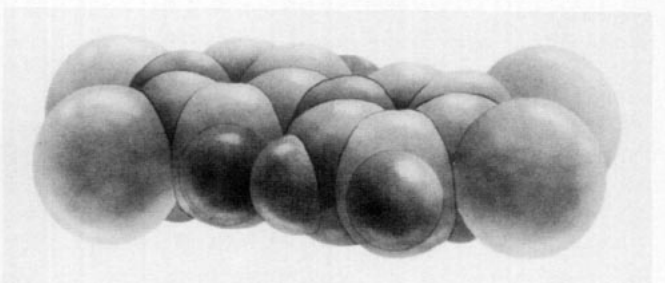

FIGURE 4. Model of 3,3',4,4'-tetrachlorobiphenyl (congener number 77) shown in coplanar conformation. Large spheres at ends of the molecule are the four chlorine atoms.

Mixed-type Inducers

The second group of congeners having enzyme inducing potencies and potential toxicities of high concern are analogs of the four non*ortho*-coplanar congeners that are still relatively coplanar but have a single *ortho*-chloro substitution (Fig. 5). These are congeners 105, 114, 118, 123, 156, 157, 167, and 189. This group of congeners has demonstrated mixed PB- and 3-MC-type inducing properties.

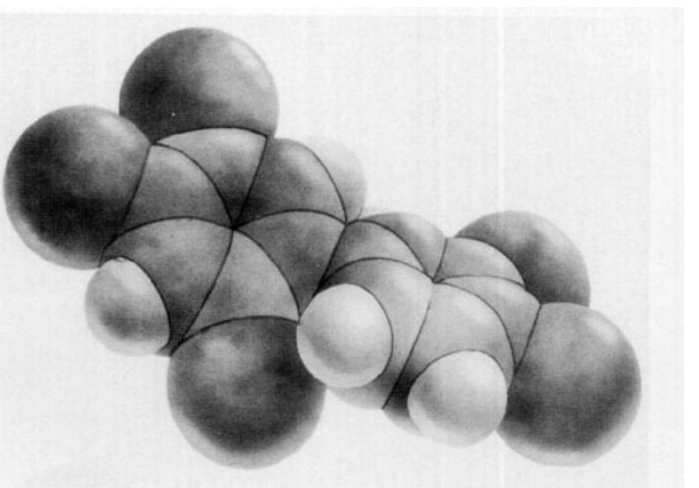

FIGURE 5. Model of 2,3',4,4',5-pentachlorobiphenyl (congener number 118), a mono-*ortho* chlorine substituted PCB having mixed-type MFO-inducing properties (see text). Rings are shown rotated at 46.6°.

Of these, congener 105 is often present in relatively high concentration in sediments, but analyses of aquatic organism tissues do not reflect this abundance (Table 1). Safe (*55*) noted that congeners 77 and 105 did not conform to the close relationship between *in vitro* and *in vivo* effects characteristic of most of the other non*ortho*-coplanar and mono-*ortho* coplanar PCBs and the most potent chlorinated dioxins and dibenzofurans. The presence of adjacent unsubstituted carbons in the biphenyl nucleus of congeners 77 and 105 is thought to facilitate metabolic degradation in mammalian tissues *in vivo* (*55*).

The di-*ortho* coplanar PCB molecules (having two *ortho*-substituted chlorines) are congeners 128, 137, 138, 153, 158, 166, 168, 170, 180, 190, 191, 194, and 205. Some of these (numbers 128, 138, 158, 166, 168, and 170) have been shown to be mixed-type inducers in mammals, although less potent than the non*ortho* coplanar and mono-*ortho* coplanar congeners (*24*). Numbers 138 and 153 (Fig. 6) are major components of technical PCB formulations and appear to have the greatest potency among the di-*ortho* coplanar congeners, both as inducers and as potential toxicants.

Besides the di-*ortho* coplanar congeners mentioned above, other congeners have been shown to be PB-type inducers (Table 1). Additionally, some congeners have not been demonstrated to be inducers but are classified as theoretical PB-type inducers according to structure-activity rules proposed by Parkinson and co-workers (*21,22,24,73,74*). The majority of PCBs apparently have no effect on mammalian systems. The 3-MC-type and mixed-type inducer PCB congeners evidently have the highest potential for toxic effect in mammals and birds and possibly in fish and invertebrates as well.

PCB Congeners of Highest Environmental Significance

Priority groupings for specific PCB congeners having highest potential environmental significance are made based upon three factors: a) potential for toxicity; b) frequency of occurrence in environmental samples; c) relative abundance in animal tissues.

Potential for toxicity is inferred by MFO induction. Pure 3-MC-type and mixed-type inducers are considered to be potentially more toxic than PB-type inducers. PB-type inducers are considered potentially more toxic than weak inducers and noninducers. [Classification of PCB congeners according to MFO-inducing capability is based on Safe et al. (*18,24*), Albro and McKinney (*19*), Goldstein (*20*), and Parkinson et al. (*21–23*).]

Frequency of occurrence in environmental samples is determined from a PCB congener database (Joan U. Clarke, unpublished) developed from information reported in the scientific literature. Environmental samples refer to sediments, water, or organisms collected in the field, as opposed to samples resulting from laboratory exposures to PCBs. At present, 59 literature references included in the database report information on specific PCB congeners in environmental samples. Congeners are considered to occur frequently if reported by at least 20% (11 of 59) of the references listing specific congeners in environmental samples.

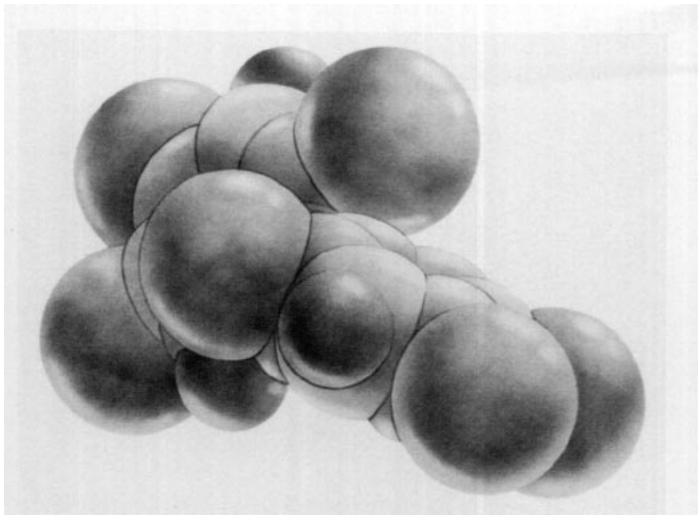

FIGURE 6. Model of 2,2',4,4',5,5'-hexachlorobiphenyl (congener number 153), a di-*ortho* chlorine substituted PCB having PB-type MFO-inducing properties. Rings are shown rotated in a noncoplanar orientation. All six chlorine atoms are visable (the largest spheres on the model).

Several sources were used for information on the relative abundance of specific congeners in animal tissues. A total of 41 single congeners and six mixtures of congeners that co-eluted (mixed peaks) were quantitated in fathead minnows exposed for 77 days to natural sediments contaminated with PCBs from an industrial discharge (*75*). Seventy-two congeners were quantitated in oligochaetes, carp, and ducks from the Detroit River, MI (*76*). Percent of total PCBs was reported for 43 congeners and 11 mixed peaks in samples of seston, shrimp, plaice, and porpoise from the Dutch Wadden Sea (*77*). Thirty-six congeners and two mixed peaks were quantitated in caddisfly larvae from the upper Hudson River, NY (*25*). All 209 congeners were included as instrument calibration standards for analysis of composited human milk samples from Michigan, and percent of total PCBs was reported for each congener (*27*). Finally, percent of total PCBs was reported for 55 congeners in human adipose tissue from people living in southwestern Sweden (*78*). Table 1 presents relative abundances of specific congeners in tissues as percent of total PCBs reported or calculated from these sources. When congeners were expressed as concentrations rather than as percent of total PCBs, percents were calculated from total PCBs as the sum of the reported individual congener and mixed-peak concentrations. Congeners considered relatively abundant comprise at least 2% of total PCBs in one or more reported tissue analyses.

Table 1 contains information for all 209 PCB congeners. Those congeners meeting the criteria for potential toxicity, frequency of occurrence, and relative abundance are footnoted in Table 1 and Appendix A and grouped according to priority in Table 2. Based on this evaluation, 36 PCB congeners were assigned to four priority groups. We consider these congeners most appropriate for use in the regulatory evaluation of environmental samples such as water, tissues of fish and other wildlife, and dredged sedi-

Table 1. PCB congeners: Frequency of environmental occurrence and relative abundance in animal and human tissues.

IUPAC no.	Isomer group[b]	Inducer type[c]	Environmental occurrences[d]	Percent of total PCB in sample[a]										
				Fathead minnows (75)	Oligochaetes (76)	Carp (76)	Ducks (76)	Seston (77)	Shrimp (77)	Plaice (77)	Porpoise (77)	Insect larvae (25)	Human milk (27)	Human fat (78)
1	1		3	—	—	—	—	—	—	—	—	1.2	0	—
2	1		1	—	—	—	—	—	—	—	—	—	0	—
3	1		1	—	—	—	—	—	—	—	—	—	0	—
4	2		5	0	0	3.8	0.17	—	—	—	—	3.8	0	—
5	2		4	1.2	—	—	—	1.6[e]	0	0	0	—	0	—
6	2		3	0.55	—	—	—	—	—	—	—	0.27	0	—
7	2		3	—	0	0.09	0.11	—	—	—	—	—	0	—
8	2		4	0.09	—	—	—	1.6[e]	0	0	0	0.86	0	—
9	2		2	0.17	—	—	—	—	—	—	—	—	0	—
10	2		2	—	—	—	—	—	—	—	—	—	0	—
11	2	Wk PB	1	—	—	—	—	—	—	—	—	—	0	—
12	2		1	—	—	—	—	—	—	—	—	—	0	—
13	2		1	—	—	—	—	—	—	—	—	—	0	—
14	2	Wk PB	0	—	—	—	—	—	—	—	—	—	0	—
15	2	Wk PB	5	2.1	—	—	—	2.1	0.8	0	0	0.94	0	—
16	3		5	0	—	—	—	—	—	—	—	0.13[f]	0	—
17	3		6	4.0	1.0	2.1	0	—	—	—	—	1.1	0	—
18[g]	3		13	0.93	1.4	0.87	0.17	2.1	0.5	0	0	2.2	0	—
19	3		2	—	—	—	—	2.6	0	0	0	—	0	—
20	3		5	6.1[h]	—	—	—	—	—	—	—	2.4[f]	0	—
21	3		2	—	—	—	—	1.4[e]	0	0	0	—	0	—
22	3		6	0.80	0.36	0.13	0.03	—	—	—	—	4.8	0.65	—
23	3		0	—	—	—	—	—	—	—	—	—	0	—
24	3		2	—	—	—	—	2.1	0	0	0	—	0	—
25	3		4	9.9	—	—	—	—	—	—	—	3.2	0	—
26	3		8	7.5	0	0.38	0.05	2.8	7.8	1.1	0.6	1.1	0	—
27	3		4	—	—	—	—	—	—	—	—	0.13[f]	0	—
28	3		10	6.1[h]	—	—	—	1.4[e]	1.2[e]	0.3[e]	0	2.4[f]	8.8	—
29	3		2	—	—	—	—	2.1	0	0	0	—	0	—
30	3		0	—	—	—	—	—	—	—	—	—	0	—
31	3		4	—	5.6	2.1	5.7	1.4	1.0	0.4	0	—	0	—
32	3		4	1.1	—	—	—	—	—	—	—	3.2	0	—
33	3		5	—	1.6	0.54	0.20	1.4[e]	0	0	0	—	2.2	—
34	3		4	6.2	—	—	—	—	—	—	—	—	0	—
35	3		0	—	—	—	—	—	—	—	—	—	0	—
36	3		2	—	—	—	—	—	—	—	—	—	0	—
37[g]	3	Mixed	5	—	—	—	—	2.1[e]	1.0[e]	0.2[e]	0	—	2.9	—
38	3		0	—	—	—	—	—	—	—	—	—	0	—
39	3		1	—	—	—	—	—	—	—	—	—	0	—
40	4		7	1.2	0	0.24	0.06	1.4	1.4	0.2	0	—	0	—
41	4		7	—	—	—	—	1.4	2.2	0.3	0	—	1.3	0.66
42	4		5	—	0.77	0.57	0.06	2.1[e]	1.0[e]	0.2[e]	0	—	0	—
43	4		1	—	0	0.12	0.02	—	—	—	—	—	0	—
44	4		17	5.8	1.8	1.5	0.09	2.1	2.8	0.5	0	19.6	0.78	1.1
45	4		2	—	0.45	0.27	0	—	—	—	—	—	0	—
46	4		3	—	0.29	0.08	0.06	—	—	—	—	—	0.25	—
47	4	PB	8	3.8	0.70	0.82	0.97	4.9[e]	0.4[e]	1.0[e]	0.2[e]	3.1	0	—
48	4		3	—	0.41	0.34	0.23	—	—	—	—	—	0.37	—
49[g]	4		15	7.6	1.6	2.0	0.31	2.8	4.4	0.9	0.7	4.0	0.66	0
50	4		3	0	—	—	—	1.4[e]	1.2[e]	0.3[e]	0	1.6	0	—
51	4		3	—	—	—	—	—	—	—	—	—	0	—
52[g]	4	Wk PB	18	11.9	2.7	2.7	0.37	2.1	8.5	4.2	4.1	13.6	1.9	0
53	4		2	—	0.56	0.28	0.02	1.4[e]	0	0	0	—	0	—
54	4	Wk PB	2	—	—	—	—	—	—	—	—	—	0	—
55	4		0	—	—	—	—	—	—	—	—	—	0	—
56	4		2	1.2	—	—	—	—	—	—	—	—	0.71[i]	—
57	4		1	—	—	—	—	—	—	—	—	—	0	—
58	4		2	—	—	—	—	—	—	—	—	—	0	—
59	4		1	—	—	—	—	—	—	—	—	—	0	—
60	4		7	—	—	—	—	1.4	0.5	0.6	0	—	0.71[i]	—
61	4		3	—	—	—	—	0.7	1.2	0.8	0.1	—	0	—
62	4		0	—	—	—	—	—	—	—	—	—	0	—
63	4		2	—	0	0.16	0.27	—	—	—	—	—	0	—
64	4		5	—	0.65	1.1	0.12	—	—	—	—	—	0	0.56
65	4		0	—	—	—	—	—	—	—	—	—	0	—
66	4	PB	7	1.0	—	—	—	3.5[e]	6.9[e]	4.0[e]	2.9[e]	3.9	0	—
67	4		2	—	—	—	—	—	—	—	—	—	0	—

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Table 1. *(Continued)*

IUPAC no.	Isomer group[b]	Inducer type[c]	Environmental occurrences[d]	Percent of total PCB in sample[a]										
				Fathead minnows (75)	Oligochaetes (76)	Carp (76)	Ducks (76)	Seston (77)	Shrimp (77)	Plaice (77)	Porpoise (77)	Insect larvae (25)	Human milk (27)	Human fat (78)
68	4		1	—	—	—	—	—	—	—	—	—	0	—
69	4		0	—	—	—	—	—	—	—	—	—	0	—
70[g]	4		13	—	2.0	0.93	0.42	4.9[e]	6.0[e]	3.4[e]	0	6.1	0.61[i]	1.5
71	4		1	—	—	—	—	—	—	—	—	—	0	—
72	4		2	—	—	—	—	—	—	—	—	—	0	—
73	4		1	—	—	—	—	—	—	—	—	—	0	—
74[g]	4		4	5.8	1.1	1.3	2.5	—	—	—	—	—	11.0	—
75	4	Wk PB	2	—	—	—	—	4.9[e]	0.4[e]	1.0[e]	0.2[e]	—	0	—
76	4		2	—	—	—	—	—	—	—	—	—	0.61[i]	—
77[g]	4	3-MC	6	—	—	—	—	8.5[e]	0	16.8[e]	0	0.07	0	—
78	4		0	—	—	—	—	—	—	—	—	—	0	—
79	4		1	—	—	—	—	—	—	—	—	—	0	—
80	4	Wk PB	3	—	—	—	—	4.9[e]	6.0[e]	3.4[e]	0	—	0	—
81[g]	4	Mixed	1	—	0.07	0.12	0.30	—	—	—	—	—	0	—
82	5		6	5.7[h]	0.14	0.17	0.08	0.3	0	0.2	0.2	4.0	0	0
83	5		1	—	—	—	—	—	—	—	—	—	0	—
84	5		10	—	1.5	1.9	0.77	0.7	0.1	1.0	0.1	1.1	0	2.5
85	5	PB*	5	5.7[h]	—	—	—	—	—	—	—	2.8	0	—
86	5		3	—	—	—	—	—	—	—	—	—	0	—
87[g]	5	PB	12	2.4	0.61	1.2	0.14	0.7[e]	0.6[e]	0.4[e]	0.3[e]	2.6	0.82	2.3
88	5		1	—	—	—	—	0	0.4	0	0.1	—	0	—
89	5		2	—	—	—	—	—	—	—	—	—	0	—
90	5		4	—	—	—	—	0.7[e]	0.6[e]	0.4[e]	0.3[e]	—	0	—
91	5		4	—	—	—	—	—	—	—	—	—	0	—
92	5		4	—	—	—	—	0	0.7	0.7	1.2	—	0	1.2
93	5		0	—	—	—	—	—	—	—	—	—	0	—
94	5		2	—	—	—	—	—	—	—	—	—	0	—
95	5		8	0.46	6.1	7.0	1.9	3.5[e]	6.9[e]	4.0[e]	2.9[e]	—	0	1.2
96	5		2	—	—	—	—	4.9[e]	6.0[e]	3.4[e]	0	—	0	—
97	5		10	0.47	0.41	0.34	0.14	—	—	—	—	1.4	0	0
98	5		1	—	—	—	—	—	—	—	—	—	0	0
99[g]	5	PB*	15	1.6	—	—	—	2.1	6.0	3.3	3.5	1.6	4.8	1.9
100	5	PB*	2	—	0.25	0.05	0.12	—	—	—	—	—	0	—
101[g]	5	PB	21	2.2	2.5	3.0	0.70	4.2	6.0	7.0	3.3	1.9	0.97	4.2
102	5		3	—	—	—	—	—	—	—	—	—	0	—
103	5		1	—	—	—	—	—	—	—	—	—	0	—
104	5		0	—	—	—	—	—	—	—	—	—	0	—
105[g]	5	Mixed	9	0.62	—	—	—	2.1	0	0.9	0	—	0	1.9
106	5		2	—	—	—	—	—	—	—	—	—	0	—
107	5		2	—	—	—	—	—	—	—	—	—	0.31	—
108	5		2	—	—	—	—	—	—	—	—	—	0	—
109	5		1	—	—	—	—	—	—	—	—	—	0	—
110	5		6	—	—	—	—	8.5[e]	0	16.8[e]	0	—	1.0	4.7
111	5		0	—	—	—	—	—	—	—	—	—	0	—
112	5		1	—	—	—	—	—	—	—	—	—	0	—
113	5		1	—	—	—	—	—	—	—	—	—	0	—
114[g]	5	Mixed	3	—	0	0.06	0.15	—	—	—	—	—	0.33	—
115	5		1	—	—	—	—	—	—	—	—	—	0	—
116	5		2	—	—	—	—	0.7[e]	0.6[e]	0.4[e]	0.3[e]	—	0	—
117	5		0	—	—	—	—	—	—	—	—	—	0	—
118[g]	5	Mixed	16	0.95	1.6	2.4	4.7	1.4	3.0	14.0	2.2	—	6.5	5.4
119[g]	5	Mixed	3	—	0	0.09	0.13	—	—	—	—	—	0.08	—
120	5		2	—	—	—	—	0.7	3.0	0.5	0.3	—	0	—
121	5		0	—	—	—	—	—	—	—	—	—	0	—
122	5		2	—	—	—	—	—	—	—	—	—	0.53	—
123[g]	5	Mixed	1	—	—	—	—	2.1[e]	1.0[e]	15.8[e]	7.0[e]	—	0	—
124	5		1	—	—	—	—	—	—	—	—	—	0	—
125	5		0	—	—	—	—	—	—	—	—	—	0	—
126[g]	5	3-MC	3	—	—	—	—	—	—	—	—	—	0	—
127	5		0	—	—	—	—	—	—	—	—	—	0	—
128[g]	6	Mixed	13	0.28	0.47	0.76	1.7	1.4	0.2	0.1	1.6	0.38	0.33	0.81
129	6		6	—	0.14	0.17	0	—	—	—	—	—	0	—
130	6		3	—	—	—	—	—	—	—	—	—	0.59	0
131	6		2	0.05	0	1.7	0.94	—	—	—	—	—	0	—
132	6		8	0.83	—	—	—	2.8	0	1.4	2.6	0.94	0	0.15
133	6	PB	3	—	—	—	—	—	—	—	—	—	0	—
134	6		6	—	0.20	0.24	0	—	—	—	—	0.13	0	0.05

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Table 1. *(Continued)*

IUPAC no.	Isomer group[b]	Inducer type[c]	Environmental occurrences[d]	Percent of total PCB in sample[a]										
				Fathead minnows (75)	Oligochaetes (76)	Carp (76)	Ducks (76)	Seston (77)	Shrimp (77)	Plaice (77)	Porpoise (77)	Insect larvae (25)	Human milk (27)	Human fat (78)
135	6		4	—	—	—	—	—	—	—	—	—	0.51[i]	1.0
136	6	Wk PB	7	0.55	0.77	1.1	0.13	0	0	0.2	0.3	—	0	0
137	6	PB	8	—	1.7	0.43	0.88	—	—	—	—	—	0.87	—
138[g]	6	Mixed	18	0	5.9	5.8	9.2	4.9	6.4	6.1	16.7	1.6	10.0	14.0
139	6	PB*	1	—	—	—	—	—	—	—	—	—	0	—
140	6	PB*	1	—	—	—	—	—	—	—	—	—	0	—
141	6		9	1.1[g]	1.4	1.6	0.42	1.4	1.0	0.9	0.2	—	0.29	—
142	6		0	—	—	—	—	—	—	—	—	—	0	—
143	6		1	—	—	—	—	—	—	—	—	—	0	—
144	6		5	—	0.81	1.2	0.19	—	—	—	—	—	0.51[i]	—
145	6		0	—	—	—	—	—	—	—	—	—	0	—
146	6	Wk PB*	4	—	1.0	1.3	2.6	—	—	—	—	—	1.9	2.7
147	6		3	—	—	—	—	—	—	—	—	—	0	—
148	6		1	—	—	—	—	—	—	—	—	—	0	—
149	6		9	1.5	4.5	5.1	1.8	2.1[e]	1.0[e]	15.8[e]	7.0[e]	—	0	0.13
150	6		1	—	—	—	—	—	—	—	—	—	0	—
151[g]	6	Wk PB	12	0.87	2.1	2.1	0.23	1.4	6.0	1.9	2.2	0.50	0.59	0.43
152	6		2	—	—	—	—	—	—	—	—	—	0	—
153[g]	6	PB	22	1.1[h]	9.9	11.1	18.2	4.2	6.4	6.6	22.5	0.54	12.0	21.5
154	6	PB	1	—	—	—	—	—	—	—	—	—	0	—
155	6	Wk PB	0	—	—	—	—	—	—	—	—	—	0	—
156[g]	6	Mixed	13	0.15	0.36	0.36	0.81	—	—	—	—	0.25	4.9	2.0
157[g]	6	Mixed	1	—	—	—	—	—	—	—	—	—	0.47	—
158[g]	6	Mixed	5	—	0.56	0.64	1.0	—	—	—	—	0.38	0.55	—
159	6	Wk PB	2	—	—	—	—	—	—	—	—	—	0	—
160	6		0	—	—	—	—	—	—	—	—	—	0	—
161	6		1	—	—	—	—	—	—	—	—	—	0	—
162	6		0	—	—	—	—	—	—	—	—	—	0	—
163	6	PB	1	—	—	—	—	—	—	—	—	—	0	—
164	6		0	—	—	—	—	—	—	—	—	—	0	—
165	6	PB	1	—	—	—	—	—	—	—	—	—	0	—
166	6	Mixed	0	—	—	—	—	—	—	—	—	—	0	—
167[g]	6	Mixed	5	0.05	—	—	—	—	—	—	—	—	0.85	0.49
168[g]	6	Mixed	1	—	—	—	—	—	—	—	—	—	0	—
169[g]	6	3-MC	3	—	—	—	—	—	—	—	—	—	0	—
170[g]	7	Mixed	16	0.12	5.6	5.2	8.9	2.8	1.4	1.1	3.5	—	5.3	3.9
171	7	PB*	5	0.16	—	—	—	—	—	—	—	—	0.37[j]	0.57
172	7		8	—	0.54	0.48	0.87	—	—	—	—	—	0.31	1.2
173	7		4	—	0.07	0.06	0.03	—	—	—	—	—	0	—
174	7		8	—	2.9	2.4	1.0	1.4	0.2	0.1	1.8	—	0.39	0
175	7		2	—	0.20	0.13	0.20	—	—	—	—	—	0	—
176	7		7	0.17	1.6	0.37	0.34	0	0.3	0	0.4	2.4	0	0
177[g]	7		11	—	1.4	1.3	1.6	1.4	1.0	0.2	1.8	—	0.61	1.3
178	7		4	0.43	—	—	—	—	—	—	—	—	0	0.90
179	7		7	—	—	—	—	0.5	0.2	0.9	0.3	—	0	0
180	7	PB	15	0.30	7.0	7.0	12.0	3.5	2.0	1.9	7.5	—	5.3	7.7
181	7	PB*	1	—	—	—	—	—	—	—	—	—	0	—
182	7	PB*	1	—	—	—	—	—	—	—	—	—	0	—
183[g]	7	PB*	11	—	3.2	2.2	3.9	0.7	0.2	0.5	1.8	—	1.4	0.81
184	7	PB*	0	—	—	—	—	—	—	—	—	—	0	—
185	7		4	—	0.41	0.45	0.16	—	—	—	—	—	0.11	—
186	7		0	—	—	—	—	—	—	—	—	—	0	—
187[g]	7		13	—	5.4	3.9	4.6	1.4	3.0	2.3	4.0	—	1.5	3.5
188	7		1	—	—	—	—	—	—	—	—	—	0	—
189[g]	7	Mixed	4	—	0.14	0.09	0.17	—	—	—	—	—	2.4	0
190	7	PB	1	—	—	—	—	—	—	—	—	—	0	—
191	7	PB	3	—	0.43	0.28	0.46	—	—	—	—	—	0.90	—
192	7		1	—	—	—	—	—	—	—	—	—	0	—
193	7		4	—	0.81	0.31	0.52	0.2[e]	0.2[e]	0.2[e]	2.0[e]	—	0.19	—
194[g]	8	PB	12	—	0.77	0.58	1.4	0.6	0.1	0	1.8	—	0.48	1.7
195	8	PB	9	—	0.38	0.33	0.65	—	—	—	—	—	0.31	0.31
196	8	PB*	8	—	—	—	—	0.6	0.2	0.1	1.8	—	0.18	0.94
197	8	PB*	0	—	—	—	—	—	—	—	—	—	0	0
198	8		7	—	0.61	0.17	0.28	—	—	—	—	—	0	—
199	8		3	—	0.07	0.03	0.01	—	—	—	—	—	0	0
200	8		3	—	—	—	—	—	—	—	—	—	0	0
201[g]	8		11	—	1.7	1.3	2.4	0.7	0.2	0	1.5	0.22	0.85	0.77

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Table 1. *(Continued)*

IUPAC no.	Isomer group[b]	Inducer type[c]	Environmental occurrences[d]	Percent of total PCB in sample[a]										
				Fathead minnows (75)	Oligochaetes (76)	Carp (76)	Ducks (76)	Seston (77)	Shrimp (77)	Plaice (77)	Porpoise (77)	Insect larvae (25)	Human milk (27)	Human fat (78)
202	8		7	—	0.54	0.55	0.76	0.2[e]	0.2[e]	0.2[e]	2.0[e]	—	0.37[i]	0
203	8	PB*	3	—	—	—	—	—	—	—	—	—	0.79	0.46
204	8	PB*	1	—	—	—	—	—	—	—	—	—	0	—
205	8	PB	2	—	0.11	0.04	0.08	—	—	—	—	—	0.06	—
206	9	PB*	6	—	0.29	0.12	0.35	0.1	0	0	0.4	—	0.24	—
207	9	PB*	2	—	0.02	0.01	0.03	—	—	—	—	—	0	0
208	9		1	—	—	—	—	—	—	—	—	—	0	0
209	10	PB*	5	—	—	—	—	0.5	0.1	0	0.3	—	0.09	0.62

[a]Total PCB = sum of individual congener concentrations.
[b]Isomer groups are defined by the number of chlorine atoms in the molecule.
[c]PB, phenobarbital-type; wk BP, weak phenobarbital-type or inactive; PB*, theoretical phenobarbital-type according to structure-activity rules (74); 3-MC, 3-methylcholanthrene-type; mixed, mixed phenobarbital- and 3-methylcholanthrene-type microsomal enzyme inducers.
[d]Number of references (out of 59 literature references giving information on PCB congeners) reporting occurrence in environmental samples.
[e]Co-eluting congeners reported in Duinker and Hillebrand (77): 5 and 8; 28 and 50; 21, 33, and 53; 47 and 75; 37 and 42; 70, 80, and 96; 95 and 66; 87, 90, and 116; 110 and 77; 149 and 123; 202 and 193.
[f]Mixed-congener peaks reported in Bush et al. (25): 16 and 27, 20 and 28.
[g]Congeners meeting the criteria for potential toxicity, frequency of occurrence, and relative abundance.
[h]Chromatographic analysis of samples in Clarke et al. (75) did not resolve peaks corresponding to congeners 20 and 28, 82 and 85, or 141 and 153.
[i]Mixed-congener peaks reported in Safe et al. (27): 56 and 60; 70 and 76; 135 and 144; 171 and 202.

ments. The 36 congeners are selected based on environmental relevance, not on analytical considerations.

In Table 2, the Group 1 or highest priority congeners, are those that are most likely to contribute to adverse biological effects due to their presence in environmental samples. Group 1 congeners fall into two classifications. Group 1A comprises the three pure 3-MC-type inducers, numbers 77, 126, and 169. Although these congeners have been reported rarely in environmental samples and only in the parts per trillion range, the very high individual toxicities of the three warrant special consideration. All three congeners have been identified as components of technical PCB formulations (*79–81*).

Group 1B congeners, numbers 105, 118, 128, 138, 156, and 170, are mixed-type inducers that have been reported frequently in environmental matrices and most are relatively abundant as well. Except for number 105, these congeners occur in nearly all of the samples included in Table 1 and individually represent as much as 16% of total PCBs reported in animal tissues. Collectively, Group 1 congeners make up 24 to 27% of total PCBs in the birds and mammals of Table 1, with a lesser representation (as little as 1.5%) in fish and invertebrates. Congener 105 is the mono-*ortho*-pentachlorobiphenyl analogue of number 77 and has a higher receptor protein binding affinity and nearly the same AHH and EROD induction potency as does number 77 (*24*). Because congener 105 has such high potential for toxicity it is included in Group 1B despite its reported lesser environmental occurrence than others in that group.

Group 2 consists of known and predicted PB-type MFO inducers that have numerous reported environmental occurrences, and most are relatively abundant in tissues. These include numbers 87, 99, 101, 153, 180, 183, and 194. Group 2 congeners occur in most of the samples listed in Table 1. Individually they comprise up to 22% of total PCBs in animal tissues. As a group, these congeners contribute 26 to 41% of total PCB in the bird and mammal samples and seven to 25% of total PCBs in fish and invertebrates.

Except for congeners 77 (a tetrachlorobiphenyl) and 194 (an octachlorobiphenyl), all of the congeners in Groups 1 and 2 are members of the penta-, hexa, and heptachlorobiphenyl isomer groups. The less chlorinated PCBs (those having one to four chlorines) are for the most part nontoxic. Many of these congeners may be taken up readily, but are also readily eliminated by organisms and are not bioaccumulated to a great extent. Most of the highly chlorinated congeners (those having seven to ten chlorines) occur in low concentrations in the environment, are tightly bound with soil and sediment, and tend to be less bioavailable. The 16 Group 1 and 2 congeners taken together account for as much as 66% of total PCBs in animal tissues. In particular, congeners 138 and 153 are major components of technical PCB formulations (*24*) and together account for over 20% of total PCBs in several tissue samples (almost 40% in porpoise).

Congeners assigned to Group 3 are weak or noninducers but occur frequently or represent at least 10% of the total PCBs in tissue samples. Group 3 congeners are most abundant in fish and invertebrate samples of Table 1, collectively contributing from 20 to 48% of the total PCBs. Bird and mammal tissues generally have lower Group 3 abundances, ranging from 13 to 19%. Group 3 congeners individually represent up to 20% of total PCBs in tissues. Group 3 spans the isomer groups from tri- through octachlorobiphenyl.

Group 4 consists of mixed-type inducers that have few reported environmental occurrences. These congeners have low relative abundance in tissue samples (Table 1). Group 4 congeners are included because of their potential for toxicity.

Appendix A. Numbering of Polychlorinated Biphenyl Congeners.[a]

No.	Structure
	Monochlorobiphenyls
1	2
2	3
3	4
	Dichlorobiphenyls
4	2,2′
5	2,3
6	2,3′
7	2,4
8	2,4′
9	2,5
10	2,6
11	3,3′
12	3,4
13	3,4′
14	3,5
15	4,4′
	Trichlorobiphenyls
16	2,2′;3
17	2,2′;4
18[a]	2,2′;5
19	2,2′;6
20	2,3,3′
21	2,3,4
22	2,3,4′
23	2,3,5
24	2,3,6
25	2,3′;4
26	2,3′;5
27	2,3′;6
28	2,4,4′
29	2,4,5
30	2,4,6
31	2,4′;5
32	2,4′;6
33	2′;3,4
34	2′;3,5
35	3,3′;4
36	3,3′;5
37[a]	3,4,4′
38	3,4,5′
39	3,4′;5
	Tetrachlorobiphenyls
40	2,2′;3,3′
41	2,2′;3,4
42	2,2′;3,4′
43[a]	2,2′;3,5
44	2,2′;3,5′
45	2,2′;3,6
46	2,2′;3,6′
47	2,2′;4,4′
48	2,2′;4,5
49[a]	2,2′;4,5′
50	2,2′;4,6
51	2,2′;4,6′
	Tetrachlorobiphenyls
52[a]	2,2′;5,5′
53	2,2′;5,6′
54	2,2′;6,6′
55	2,3,3′;4
56	2,3,3′;4′
57	2,3,3′;5
58	2,3,3′;5′
59	2,3,3′;6
60	2,3,4,4′
61	2,3,4,5
62	2,3,4,6
63	2,3,4′;5
64	2,3,4′;6
65	2,3,5,6
66	2,3′;4,4′
67	2,3′;4,5
68	2,3′;4,5′
69	2,3′;4,6
70[a]	2,3′;4′;5
71	2,3′;4′;6
72	2,3′;5,5′
73	2,3′;5′;6
74[a]	2,4,4′;5
75	2,4,4′;6
76	2′;3,4,5
77[a]	3,3′;4,4′
78	3,3′;4,5
79	3,3′;4,5′
80	3,3′;5,5′
81[a]	3,4,4′;5
	Pentachlorobiphenyls
82	2,2′;3,3′;4
83	2,2′;3,3′;5
84	2,2′;3,3′;6
85	2,2′;3,4,4′
86	2,2′;3,4,5
87[a]	2,2′;3,4,5′
88	2,2′;3,4,6
89	2,2′;3,4,6′
90	2,2′;3,4′;5
91	2,2′;3,4′;6
92	2,2′;3,5,5′
93	2,2′;3,5,6
94	2,2′;3,5,6′
95	2,2′;3,5′;6
96	2,2′;3,6,6′
97	2,2′;3′;4,5
98	2,2′;3′;4,6
99[a]	2,2′;4,4′;5
100	2,2′;4,4′;6
101[a]	2,2′;4,5,5′
102	2,2′;4,5,6′
103	2,2′;4,5′;6
104	2,2′;4,6,6′
	Pentachlorobiphenyls
105[a]	2,3,3′;4,4′
106	2,3,3′;4,5
107	2,3,3′;4′;5
108	2,3,3′;4,5′
109	2,3,3′;4,6
110	2,3,3′;4′;6
111	2,3,3′;5,5′
112	2,3,3′;5,6
113	2,3,3′;5′;6
114[a]	2,3,4,4′;5
115	2,3,4,4′;6
116	2,3,4,5,6
117	2,3,4′;5,6
118[a]	2,3′;4,4′;5
119[a]	2,3′;4,4′;6
120	2,3′;4,5,5′
121	2,3′;4,5′;6
122	2′;3,3′;4,5
123[a]	2′;3,4,4′;5
124	2′;3,4,5,5′
125	2′;3,4,5,6′
126[a]	3,3′;4,4′;5
127	3,3′;4,5,5′
	Hexachlorobiphenyls
128[a]	2,2′;3,3′;4,4′
129	2,2′;3,3′;4,5
130	2,2′;3,3′;4,5′
131	2,2′;3,3′;4,6
132	2,2′;3,3′;4,6′
133	2,2′;3,3′;5,5′
134	2,2′;3,3′;5,6
135	2,2′;3,3′;5,6′
136	2,2′;3,3′;6,6′
137	2,2′;3,4,4′;5
138[a]	2,2′;3,4,4′;5′
139	2,2′;3,4,4′;6
140	2,2′;3,4,4′;6′
141	2,2′;3,4,5,5′
142	2,2′;3,4,5,6
143	2,2′;3,4,5,6′
144	2,2′;3,4,5′;6
145	2,2′;3,4,6,6′
146	2,2′;3,4′;5,5′
147	2,2′;3,4′;5,6
148	2,2′;3,4′;5,6′
149	2,2′;3,4′;5′;6
150	2,2′;3,4′;6,6′
151[a]	2,2′;3,5,5′;6
152	2,2′;3,5,6,6′
153[a]	2,2′;4,4′;5,5′
154	2,2′;4,4′;5,6′
155	2,2′;4,4′;6,6′
156[a]	2,3,3′;4,4′;5
157[a]	2,3,3′;4,4′;5′
158[a]	2,3,3′;4,4′;6
159	2,3,3′;4,5,5′
160	2,3,3′;4,5,6
	Hexachlorobiphenyls
161	2,3,3′;4,5′;6
162	2,3,3′;4′;5,5′
163	2,3,3′;4′;5,6
164	2,3,3′;4′;5′;6
165	2,3,3′;5,5′;6
166	2,3,4,4′;5,6
167[a]	2,3′;4,4′;5,5′
168[a]	2,3′;4,4′;5′;6
169[a]	3,3′;4,4′;5,5′
	Heptachlorobiphenyls
170[a]	2,2′;3,3′;4,4′;5
171	2,2′;3,3′;4,4′;6
172	2,2′;3,3′;4,5,5′
173	2,2′;3,3′;4,5,6
174	2,2′;3,3′;4,5,6′
175	2,2′;3,3′;4,5′;6
176	2,2′;3,3′;4,6,6′
177[a]	2,2′;3,3′;4′;5,6
178	2,2′;3,3′;5,5′;6
179	2,2′;3,3′;5,6,6′
180[a]	2,2′;3,4,4′;5,5′
181	2,2′;3,4,4′;5,6
182	2,2′;3,4,4′;5,6′
183[a]	2,2′;3,4,4′;5′;6
184	2,2′;3,4,4′;6,6′
185	2,2′;3,4,5,5′;6
186	2,2′;3,4,5,6,6′
187[a]	2,2′;3,4′;5,5′;6
188	2,2′;3,4′;5,6,6′
189[a]	2,3,3′;4,4′;5,5′
190	2,3,3′;4,4′;5,6
191	2,3,3′;4,4′;5′;6
192	2,3,3′;4,5,5′;6
193	2,3,3′;4′;5,5′;6
	Octachlorobiphenyls
194[a]	2,2′;3,3′;4,4′;5,5′
195	2,2′;3,3′;4,4′;5,6
196	2,2′;3,3′;4,4′;5,6′
197	2,2′;3,3′;4,4′;6,6′
198	2,2′;3,3′;4,5,5′;6
199	2,2′;3,3′;4,5,6,6′
200	2,2′;3,3′;4,5′;6,6′
201[a]	2,2′;3,3′;4,5,5′;6′
202	2,2′;3,3′;5,5′;6,6′
203	2,2′;3,4,4′;5,5′;6
204	2,2′;3,4,4′;5,6,6′
205	2,3,3′;4,4′;5,5′;6
	Nonachlorobiphenyls
206	2,2′;3,3′;4,4′;5,5′;6
207	2,2′;3,3′;4,4′;5,6,6′
208	2,2′;3,3′;4,5,5′;6,6′
	Decachlorobiphenyl
209	2,2′;3,3′;4,4′;5,5′;6,6′

[a]See Stalling et al. (*11*).
[b]Congeners listed in Table 2.

Evaluation of PCB-Contaminated Environmental Samples

An analysis for specific PCB congeners in environmental samples allows a more meaningful assessment for possibly unacceptable adverse biological effects by focusing only on those congeners that are prevalent in the environment, are preferentially bioaccumulated, or are potentially toxic. We have assigned the most environmentally

Table 2. Priority groups of PCB congeners of highest concern as environmental contaminants based on potential toxicity, frequency of occurrence and abundance, and suggested for inclusion in analysis of environmental materials for regulatory purposes.

IUPAC no.			
Group 1	Group 2	Group 3	Group 4
A	87[a,b]	18[a]	37[b]
77[a,b]	99[b]	44[a,b,c]	81[c]
126[b]	101[a,b,c]	49[a,b,c]	114[a,b,c]
169[b,c]	153[a,b]	52[a,b,c]	119
	180[a,b]	70[b]	123
B	183[a,b,c]	74[b]	157
105[a,b]	194[a,c]	151[a,c]	158[b]
118[a,b]		177[c]	167
128[a,b,c]		187[a,c]	168
138[a,b,c]		201[a]	189[a,b,c]
156[a,b]			
170[a,b,c]			

[a]*Congeners included in Canadian Standard CLB-1. The remaining congeners* making up CLB-1 are nos. 15, 31, 40, 54, 60, 86, 103, 121, 129, 137, 141, 143, 154, 159, 171, 173, 182, 185, 191, 195, 196, 200, 202, 203, 205, 206, 207, 208, and 209.

[b]Congeners suggested for inclusion in a selective congener analysis for human foodstuffs and tissues (*83*). Other congeners listed were 8, 28, 60, 66, 82, 166, 179, and 187.

[c]Identified as prevalent congeners that elute (or probably elute) as single-congener peaks from a single SE-54 glass capillary column using GC/ECD (*81*). Others listed were 24, 29, 26, and 84.

threatening of these to Groups 1 and 2. A calibration standard for congener-specific analysis of PCB-contaminated environmental materials would ideally include all of the compounds in Groups 1 and 2. The congeners in Group 3 are important in terms of environmental prevalence and relative abundance in animal tissues. Group 4 congeners may be of lesser significance in the environment but are toxicologically active.

An analytical instrument calibration standard for PCB congener-specific analysis by capillary column gas chromatography has been developed in Canada (*82*). The Canadian standard mixture, CLB-1, contains 51 congeners, including 13 of the 16 congeners in Groups 1 and 2 (Table 2). Nine of the remaining 20 congeners in Groups 3 and 4 are also included in the Canadian standard. Not included are numbers 126 and 169, two of the three most toxic congeners that make up Group 1A. As yet, the United States has not adopted a selected PCB congener standard mixture. However, most of the congeners in the four priority groups of Table 2 are commercially available and a standardization cocktail could be prepared, but at a high cost. The cost factor coupled with quality assurance considerations suggests that a standard mixture similar to the Canadian CLB-1 should be developed.

The specific PCB congeners identified here as being of primary concern as environmental contaminants were selected based on current knowledge. Congener-specific PCB analyses are not conducted routinely, and there is not a great wealth of data in the literature concerning concentrations of individual congeners in environmental samples. While this paper was in preparation and then in review, two articles appeared in the scientific literature differing in important respects but also addressing the subjects of environmental occurrence of PCB congeners and the desirability of congener-specific analysis (*81,83*). Both considered the necessity of using potential toxicity as a criterion for inclusion of PCB congeners in an analysis, and both used MFO induction or the coplanarity of rings as indications of toxic potential. Jones (*83*) worked from a data set that was largely different from that used here and concluded with a list containing 32 congeners. With the exception of number 194, Jones included all of the congeners we assigned to priority Groups 1 and 2 (Table 2). Of the remaining 21 congeners in priority groups 3 and 4, Jones listed 10. Duinker, Schultz, and Petrick (*81*) considered the difficulties in separating mixed peaks as a criterion for inclusion of congeners, but also suggested that toxicity be used as a criterion for analysis of environmental samples. Sixteen of the 36 congeners we have prioritized were identified as being capable of unambiguous analysis by conventional means (Table 2). The remaining 20 congeners present varying degrees of difficulty in analysis and some may not be analyzable by current methods.

Somewhat different patterns of environmental prevalence or relative abundances of congeners in animal tissues may emerge as a result of additional studies. Furthermore, toxicity and bioavailability of PCB congeners are exceedingly complex issues. Potential for toxicity, particularly to nonmammalian species, is probably not fully described by classification of PCB congeners according to type of mammalian microsomal enzyme induction. Much additional research is needed to fully characterize the bioavailability and toxicity of specific congeners or mixtures of congeners in environmental matrices under controlled laboratory conditions, as well as under more variable field conditions.

Summary

This paper presents an analysis of the potential for adverse environmental effects of specific PCB congeners. Thirty-six congeners are considered most environmentally threatening based on their frequency of occurrence in environmental samples, relative abundance in animal tissues, and potential for toxicity. Toxic potential is evidenced by type and specificity of mammalian microsomal mixed-function oxidase (MFO) induction. These congeners may be assigned to four priority groups. Group 1 includes the three pure 3-MC-type MFO inducing congeners, along with six mixed-type inducers that have been reported frequently in environmental samples and can be fairly abundant in tissues. The seven Group 2 congeners are PB-type inducers that also have numerous reported environmental occurrences and have high relative abundances, especially in avian and mammalian samples. Group 3 congeners are weak or noninducers that occur frequently or in relatively high concentrations, particularly in fish and invertebrate tissues. Group 4 includes ten mixed-typed inducers that have been reported infrequently in environmental samples and in relatively low concentrations. Group 4 congeners, though scarce in environmental matrices, are considered to be of possible concern because of their potential for toxicity.

Toxicologically relevant evaluations of PCB-contaminated environmental materials can be accomplished better by analyzing samples for specific congeners in the four priority groups as compared to analyzing as total PCBs or as Aroclor equivalents. A more meaningful assessment of a potentially unacceptable adverse ecological impact can be achieved by focusing only on those congeners that are prevalent in the environment, that are preferentially bioaccumulated, or are potentially toxic. This approach would be facilitated by the development of a standard PCB congener mixture that could be used as a reference standard during the analysis of environmental samples.

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