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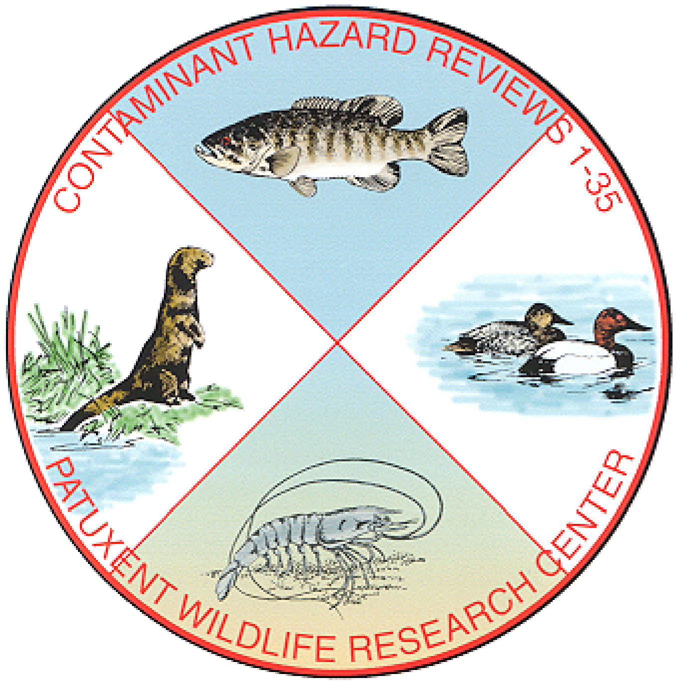

Chlordane Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review

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Tables

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Abstract

ABSTRACT.-Technical chlordane is an organochlorine compound first introduced into the United States in 1947 in a variety of formulations for use as a broad-spectrum pesticide. By 1974, about 9.5 million kilograms of chlordane were produced annually. Concern over the potential carcinogenicity of chlordane has led to sharply curtailed production. Since 1983, chlordane use in the United States has been prohibited, except for control of underground termites.

Technical chlordane consists of about 45 components, primarily *cis*-chlordane (19%), *trans*-chlordane (24%), heptachlor (10%), *cis*- and *trans*-nonachlor (7%), and various chlordane isomers (22%). Chemical analysis of technical chlordane is difficult because of analytical interferences from other organochlorine compounds, nonstandardization of analytical techniques, variations in the number and relative composition of components in weathered chlordane, and, uncertainty of structural formulas and other properties of several compounds present.

Past chlordane use, coupled with atmospheric transport as the major route of dissemination, produced global contamination of fish and wildlife resources and human populations. The chemical and its metabolites were frequently detected in all species examined, but usually at low concentrations. Residues in fish muscle sometimes exceeded the U.S. Food and Drug Administration action level of 0.3 mg/kg fresh weight recommended for human health protection. In general, chlordane in animals is highest near areas where the chemical has been applied to control termites; concentrations are highest in fat and liver, especially in predatory species.

The half-life of chlordane in water is comparatively short; *cis*-chlordane, for example, usually persists less than 18 h in solution. In soils, however, some chlordane isomers persist for 3 to 14 years because of low solubility in water, high solubility in lipids, and relatively low vapor pressure. There seems to be little accumulation of chlordane in crops grown in contaminated soils.

Chlordane is readily absorbed by warm-blooded animals through skin, diet, and inhalation, and distributed throughout the body. In general, residues of chlordane and its metabolites are not measurable in tissues 4 to 8 weeks after exposure, although metabolism rates varied significantly between species. Food chain biomagnification is usually low, except in some marine mammals. In most mammals, the metabolite oxychlordane has proven much more toxic and persistent than the parent chemical.

Many species of aquatic organisms are adversely affected at concentrations in water between 0.2 and 3.0 µg/L technical chlordane. Sensitive bird species had reduced survival on diets containing 1.5 mg chlordane per kilogram in their diet, or after a single oral dose as low as 14.1 mg chlordane per kilogram body weight. Chlordane has produced liver cancer in laboratory strains of domestic mice, but carcinogenicity has not been established in other mammals.

Chlordane criteria for protection of marine life (0.004 µg/L, 24-h mean; not to exceed 0.09 µg/L) seem satisfactory. Proposed criteria for freshwater life protection (0.0043 µg/L, 24-h mean; not to exceed 2.4 µg/L) however, overlap the range of 0.2 to 3.0 µg/L shown to adversely affect certain fish and aquatic invertebrates, suggesting that some downward modification in the maximum permissible level is needed. Chlordane criteria for protection of birds and mammals are inadequate because the data base is incomplete. Until these data become available, a reasonable substitute is the criteria proposed for human health protection, namely, daily intake not to exceed 0.001 mg chlordane per kilogram body weight, and diet not to exceed 0.3 mg chlordane per kilogram fresh weight.

Most authorities agree that more studies are needed in several areas: monitoring of oxychlordane concentrations in wildlife; interpretation of the biological significance of residue levels found in wildlife; standardization of analytical extraction and other techniques for quantitation of chlordane and its metabolites; reexamination of aquatic toxicity data where test concentrations exceeded the solubility of chlordane in water (6 to 9 µg/L); interaction effects with other agricultural chemicals; reevaluation of the cancer risk of chlordane on representative organisms at realistic environmental levels; effects of depleted soil fertility from chlordane-induced earthworm suppression; and continuance of epidemiological studies on exposed workers.

Technical chlordane is a mixture of chlorinated hydrocarbons that has been used as an insecticide since its introduction in 1947. Chlordane was the first cyclodiene insecticide to be used in agriculture and was the second most important organochlorine insecticide in the United States in 1976-77, behind toxaphene, with an estimated annual production of 9 million kilograms (Nomeir and Hajjar 1987). Chlordane is now the leading insecticide in controlling termites, with about 1.2 million homes in the United States alone treated annually for this purpose (Nomeir and Hajjar 1987).

Chlordane has been detected in human milk in Canada, Hawaii, Japan, Mexico, Mississippi, and Spain (World Health Organization [WHO] 1984; Ohno et al. 1986). Chlordane compounds have been detected in oysters from the South Atlantic Ocean and Gulf of Mexico, in fish from the Great Lakes and major river basins of the United States, in the blubber of cetaceans from the coastal waters of North America, and the Antarctic atmosphere (Kawano et al. 1988). In fact, all available evidence suggests that chlordane is ubiquitous in the environment. Air and water transport of technical chlordane has resulted in the detection of chlordane and its metabolites in rainwater, drinking water, air, surface waters, soils, sediments, plankton, earthworms, fish, shellfish, birds and their eggs, aquatic invertebrates, cats, dogs, livestock, and humans (Zitko 1978; Environmental Protection Agency 1980; Sudershan and Khan 1980; Kerkhoff and Boer 1982; Wickstrom et al. 1983; Johnson et al. 1986; Nomeir and Hajjar 1987; Suzaki et al. 1988). Despite its widespread use, persistence, and tendency to accumulate in fat, there was no firm evidence of direct lethal or sublethal effects on terrestrial vertebrate wildlife until Blus et al. (1983) recorded several chlordane-related mortalities. A North Dakota marsh treated with chlordane had decreased reproductive success and some deaths of young of several bird species but this was attributed to depletion of invertebrate prey and not to acute poisoning (Hanson 1952). More recently, chlordane was implicated as the principal toxicant in 30 pesticide poisoning cases of hawks, owls, herons, and other birds in New York between 1982 and 1986 (Stone and Okoniewski 1988).

The U.S. Environmental Protection Agency (EPA) considers chlordane as a probable human carcinogen (defined as inadequate evidence from human studies and sufficient evidence from animal studies), as judged by chlordane-induced cancer of the liver in domestic mice (Arruda et al. 1987). In 1978, EPA restricted chlordane use to subterranean termite control, nonfood plants, and root dip. Limited agricultural use was permitted until 1980. In 1987, EPA registered chlordane again, limiting its sale and use to licensed applicators for subterranean termite control (Arruda et al. 1987). However, it seems that significant home and garden use exists, especially for control of termites and undesirable lawn insects (Wood et al. 1986). Reviews on ecological and toxicological aspects of chlordane in the environment are available; particularly useful are those by Ingle (1965), Menzie (1974), National Research Council of Canada [NRCC] (1975), International Agency for Research on Cancer [IARC] (1979), EPA (1980, 1988), WHO (1984), Klaassen et al. (1986), and Nomeir and Hajjar (1987).

This report was prepared in response to requests for information on chlordane from regional environmental contaminant specialists of the U.S. Fish and Wildlife Service. It is part of a continuing series of brief reviews on chemicals in the environment, with emphasis on fishery and wildlife resources.

Chemical and Biochemical Properties

Technical chlordane (64 to 67 % chlorine) is produced by the condensation of cyclopentadiene and hexachlorocyclopentadiene to yield chlordene (Figure). Addition of chlorine across the 2-3 olefinic bond of chlordene forms *cis*-chlordane and *trans*-chlordane; substitution of chlorine into position 1 of chlordene forms heptachlor, and further addition of chlorine across the 2-3 olefinic bond forms *cis*-nonachlor and *trans*-nonachlor (Ribick and Zajicek 1983). Technical chlordane includes about 45 components. Its approximate composition is 19% *cis*-chlordane ($C_{10}H_6Cl_8$), 24% *trans*-chlordane ($C_{10}H_6Cl_8$), 21.5% chlordene isomers ($C_{10}H_6Cl_6$), 10% heptachlor ($C_{10}H_5Cl_7$), *7% cis*- and *trans*-nonachlor ($C_{10}H_5Cl_9$), 2% Diels-Alder adduct of cyclopentadiene and pentachlorocyclopentadiene, 1 % hexachlocycloropentadiene, 1 % octachlorocyclopentene, and 15.5% miscellaneous constituents (NRCC 1975; IARC 1979; EPA 1980; WHO 1984). Oxychlordane and heptachlor epoxide are toxicologically significant degradation products (Figure; Perttila et al. 1986).

Chlordane produced before 1951 contained a significant quantity of hexachlorocyclopentadiene--a toxic irritant to warm-blooded animals; chlordane produced after 1951 contains little or none of this compound (Ingle 1965). A high-purity chlordane formulation containing about 74% *cis*-chlordane and 24% *trans*-chlordane is also available (Nomeir and Hajjar 1987).

Chemical analysis of technical chlordane is difficult because of frequent variations in both the number and relative composition of components in weathered chlordane (Ribick and Zajicek 1983). Other difficulties are encountered from analytical interferences from various organochlorine compounds; furthermore, the exact structure has not been determined for a number of compounds in technical chlordane, and the majority of compounds have not been isolated or synthesized for use as comparative standards (Ribick and Zajicek 1983).

Cis-chlordane (CAS number 5103-71-9) and *trans*-chlordane (CAS number 5103-74-2) are characterized by the following properties: molecular weight of 409.76; chemical formula of ($C_{10}H_6Cl_8$); viscous, amber-colored liquid; boiling point between 104 and 105° C for *trans*-chlordane, and between 106 and 107° C for *cis*-chlordane; density of 1.59 to 1.63 at 25° C; soluble in most organic solvents, but only sparingly soluble in water, that is, 9µg/L at 25° C; vapor pressure of 0.00001 mm mercury at 25° C; and a log Kow (octanol/water partition coefficient) of 5.16 (Ingle 1965; NRCC 1975; IARC 1979; EPA 1980, 1988; WHO 1984). Pesticides containing chlordane or technical chlordane have been sold under a variety of names including 1068, Aspon, Belt, CD-68, Chlor-dan, Chlordan, Chlorindan, Chlor-kil, Chlorodane, Chlortox, Cortilanneu, Corodane, Dichlorochlordene, Dichlorodene, Dowchlor, ENT 9932, HCS 3260, Kypclor, M 140, M 410, Niran, Niran 5% granular bait, Octachlor, Octa-klor, Octaterr, Ortho-klor, Synklor, Tat Chlor 4, Topiclor 20, Toxichlor, and Velsicol 1068 (IARC 1979; Johnson and Finley 1980; Hudson et al. 1984; WHO 1984; Hill and Camardese 1986; Mayer 1987; EPA 1988).

Technical chlordane is stable under ultraviolet (UV) light, although some components, such as chlordane, heptachlor, *cis*-chlordane, and *trans*-chlordane, will form photoisomers under high intensity UV in the presence of sensitizers, such as ketones (NRCC 1975; Menzie 1978). Several compounds were measured in alfalfa grown on soils treated with chlordane, including 1,2-dichlorochlordene, oxychlordane, and photo-*cis*-chlordane, as well as the parent chlordane compounds (WHO 1984). The half-life (Tb 1/2) of *cis*-chlordane in water is comparatively short, between 1.1 and 17.5 h (Feroz and Khan 1979a). In soils, technical chlordane has a half-life ranging from 0.5 to 1.0 years for some samples, and 4 to 10 years for other samples. The lower Tb 1/2 values refer to the initial rapid disappearance of chlordane from the soil; if studies continue over several years, the remaining chlordane is relatively persistent, with a Tb 1/2 of 5 to 7 years (NRCC 1975). Measurable residues of chlordanes in soil were present more than 14 years after application (EPA 1988). Chlordane persists in soils because of its low solubility in water, relatively low vapor pressure, and high tendency to adsorb to soil particles; accordingly, soil-bound chlordanes are not likely to become serious contaminants of the lower soil strata or deep water sources (WHO 1984). Transport into the hydrosphere from contaminated soils will occur through erosion of soil particles or sediments, not by desorption and dissolution (Klaassen et al. 1986).

Chlordane is a nerve stimulant; at low chronic doses it produces hyperexcitability and lack of coordination in animals, and at high acute doses causes tremors and convulsions (Ingle 1965; Klaassen et al. 1986). Chlordane induces hepatic microsomal drug-metabolizing enzymes, resulting in enhanced biotransformation at low doses, although high doses may result in liver hypertrophy (Klaassen et al. 1986). The physiological target sites are in nerve and muscle membranes, presumably on proteins and phospholipids; the ultimate effect is axonic with membrane disruption, resulting in spasmic muscle twitching and death (Greenhalgh 1986).

Chlordane is readily absorbed by warm-blooded animals through skin, diet, and inhalation. It is quickly distributed in the body and tends to concentrate in liver and fat (WHO 1984). Up to 75% of a single oral dose of chlordane administered to rats and mice was absorbed in the gut, and up to 76% of an aerosol dose was absorbed in the respiratory tract (Nomeir and Hajjar 1987); rabbits absorbed 33% in the gut following oral administration (EPA 1988). Chlordane residues in mammals were usually not measurable 4 to 8 weeks after cessation of exposure (Ingle 1965). Chlordane persistence in human serum and whole body was estimated at 88 days and 21 days, respectively; this compares to a Tb 1/2 of about 23 days in rats fed chlordane for 56 days (EPA 1980).

Excretion kinetics of chlordane are complex, and different isomers exit through different pathways (EPA 1980, 1988). In rats, chlordane elimination was almost complete 7 days after receiving single oral doses up to 1 mg/kg body weight (BW); 24 h after treatment, 70% of the *cis*-chlordane and 60% of the *trans*-chlordane had been excreted (WHO 1984). In rodents, chlordane and its metabolites were usually excreted in feces, regardless of the administration route; the *cis*-isomer was excreted slightly faster than the *trans*-isomer, although identical metabolites seemed to be formed (EPA 1980; Menzie 1969, 1980; WHO 1984; Nomeir and

Hajjar 1987). In rabbits, however, up to 47 % of the administered dose was voided in the urine, and *cis*- and *trans*-chlordane were excreted at the same rate (Nomeir and Hajjar 1987).

Microorganisms such as *Nocardiopsis* sp., an actinomycete, can metabolize *cis*- and *trans*-chlordane to at least eight solvent-soluble substances, including dichlorochlordene, oxychlordane, heptachlor, heptachlor *endo*-epoxide, chlordene chlorohydrin, and 3-hydroxy-*trans*-chlordane (Beeman and Matsumura 1981). Based on studies of chlordane metabolism in animals, four metabolic pathways arc proposed: (1) hydroxylation to form 3-hydroxychlordane, which on dehydration forms 1,2-dichlorochlordene, with subsequent epoxidation to oxychlordane (*trans*-chlordane is converted to oxychlordane 7 times faster than is *cis*-chlordane); (2) dehydrochlorination to form heptachlor, from which heptachlor epoxide and other hydroxylation products may be formed; (3) dechlorination to monochlorodihydrochlordene; and (4) the replacement of chlorine by hydroxyl groups resulting in the formation of hydroxy metabolites, which are excreted or further transformed by conjugation with glucuronic acid (Feroz and Khan 1979a; WHO 1984; Nomeir and Hajjar 1987; EPA 1988). Metabolism of chlordanes and nonachlors to oxychlordane is orders of magnitude greater in fish-eating and carnivorous birds than in marine mammals (Kawano et al. 1988). The reasons for this are unclear and merit further research.

Trans-nonachlor, a major component of technical chlordane, was frequently found as the major chlordane residue in humans, whereas oxychlordane was the major component in rats fed technical chlordane (Nomeir and Hajjar 1987). *Trans*-nonachlor is converted efficiently by rat liver microsomes to *trans*-chlordane, but this ability is lacking in humans, resulting in the accumulation of *trans*-nonachlor in humans (Nomeir and Hajjar 1987).

Although technical chlordane is a mixture of compounds, two metabolites--heptachlor epoxide and oxychlordane--can kill birds when administered through the diet (Blus et al. 1983). These two metabolites originate from biological and physical breakdown of chlordanes in the environment, or from metabolism after ingestion. Heptachlor can result from breakdown of *cis*- and *trans*-chlordane, eventually oxidizing to heptachlor epoxide; oxychlordane can result from the breakdown of heptachlor, *cis*-chlordane, *trans*-chlordane, or *trans*-nonachlor (Blus et al. 1983). Heptachlor epoxide has been identified in soil, crops, and aquatic biota, but its presence is usually associated with the use of heptachlor, not technical chlordane--which also contains some heptachlor (NRCC 1975). Various components in technical chlordane may inhibit the formation of heptachlor epoxide or accelerate the decomposition of the epoxide, but the actual mechanisms are unclear (NRCC 1975).

In mammals, oxychlordane ($C_{10}H_4Cl_8O$) is a metabolite *of cis*- and *trans*-chlordanes and *trans*-nonachlor (Miyazaki et al. 1980), and has proven much more toxic and persistent than the parent chemicals (WHO 1984; Kawano et al. 1988). Oxychlordane has been measured in the fat of rats, dogs, and pigs fed either isomer, and in milk and cheese from cows fed alfalfa treated with technical chlordane (WHO 1984; Nomeir and Hajjar 1987; EPA 1988). Oxychlordane was isolated and identified from adipose tissues of pigs fed diets (for 90 days) containing 300 mg/kg of *cis*-chlordane or *trans*-chlordane (Schwemmer et al. 1970). Sharply elevated oxychlordane levels were detected in milk from cows fed chlordane for 60 days; when chlordane was removed from their diet, oxychlordane residues in milk dropped rapidly during the week following termination, and stabilized after 2 weeks (EPA 1980). The Tb 1/2 for oxychlordane in beef cattle grazing in heptachlor-contaminated pastures for 4 weeks was about 92 days (Petterson et al. 1988). Rats and rabbits given chlordane orally or through the diet retained the highest levels in adipose tissue, followed by liver, kidney, brain, and muscle; oxychlordane was the most persistent residue after chlordane was removed from the diet (WHO 1984; EPA 1988).

Uses

Chlordane was first produced commercially in the United States in 1947 and became available in five basic formulations, including 5% granules, oil solutions containing 2 to 200 g/L, and emulsifiable concentrates containing chlordane at 400 to 800 g/L (WHO 1984). Production of chlordane in the United States in 1971 was estimated at 11.3 million kg (Glooschenko and Lott 1977). By 1974, about 9.5 million kilograms of chlordane were used domestically to control commercial pests (35%); in homes, lawns, and gardens (30%); on corn (20%); turf (6%); potatoes (5%); tomatoes (2%); and other uses (IARC 1979). On 6 March 1978, the EPA issued a cancellation proceeding on chlordane, allowing limited use on certain crops and pests until 1 July 1983, but no use thereafter except for underground termite control (IARC 1979; EPA 1988). A similar situation exists in Japan, where the only permitted use of chlordane is for control of termites and powder post beetles (Miyazaki et al. 1980). Use in Japan is estimated at 500,000 kg a year (Yamagishi et al. 1981 b).

In Canada, chlordane had been used in soils (usually at 0.45 to 4.5 kg/ha) against corn rootworms, strawberry root weevils, wireworms, white grubs, and subterranean cutworms infesting a wide range of crops (Glooschenko and Lott 1977). In the past, at least 75 different formulations containing chlordane as the active insecticidal ingredient had been registered for sale in Canada; the most widely sold formulation, accounting for about 60% of chlordane in soils, was the 25% granular type that was used extensively for corn rootworm control (NRCC 1975). Sales of chlordane in Canada increased about tenfold between 1969 and 1971 because of restrictions on DDT and other organochlorines; however, chlordane use was restricted in Canada in 1978 (Elliott et al. 1988).

Background Concentrations

General

Chlordanes and their metabolites are ubiquitous in the environment at low concentrations, but at a high occurrence in samples analyzed. Atmospheric transport is considered to be the major route of global dissemination. Some chlordane isomers persist in soils for 3 to 15 years, although there seems to be little accumulation of chlordanes by crop plants grown in these soils. Lengthy persistence of various chlordane isomers, especially *cis*-chlordane and *trans*-nonachlor, has been reported in certain organisms, but this has varied greatly between species and tissues.

In living organisms, chlordane concentrations are usually highest in samples collected near areas where chlordane was applied to control termites or other pests, in predatory species, and in tissues with high lipid content. Food chain biomagnification is usually low except in certain marine mammals. In some fishes, chlordane levels in muscle have been sufficient to endanger fish health (100 µg/kg fresh weight) or human consumers of fish (300 µg/kg fresh weight).

Nonbiological Samples

Air and water transport of technical chlordane has resulted in the detection of chlordane and its metabolites in nonbiological samples worldwide (Table 1). Chlordane enters the atmosphere mainly through aerial applications of dust and spray formulations, soil erosion by wind, and volatilization from soil and water (WHO 1984). In aquatic systems, chlordane enters by way of surface runoff and rainfall; chlordane is rapidly adsorbed onto bottom sediments, where it persists (WHO 1984). Atmospheric transport of chlordanes is considered the major route of global dissemination (Pyysalo et al. 1981; Wickstrom et al. 1981). Levels of chlordane compounds in the marine atmosphere of the Southern Hemisphere are nearly the same as those of DDT and its metabolites; this strongly suggests that chlordane compounds are globally distributed and dispersed (Kawano et al. 1985). The yearly input of *cis*-chlordane to the Arctic Ocean from atmospheric sources is estimated at 3,000 kg; if *cis*-chlordane constitutes 19% of technical chlordane, then more than 600,000 kg of technical chlordane has entered the Arctic Ocean since 1948 (Hoff and Chan 1986). Chlordane is frequently measured in the air of buildings where the compound has been used for insect control (WHO 1984). Chlordane has been found in household dust in the homes of farmers and pesticide formulators at exceedingly high mean levels: 5.8 to 23.1 mg/kg air-dried dust (WHO 1984).

Chlordane has been detected in both groundwater and surface water at low levels of 0.001 to 0.01 µg/L (EPA 1988). A high frequency of chlordane was detected in seawater samples collected from a Hawaiian marina: up to 90% of all samples contained *cis*-chlordane, and 68 % contained *trans*-chlordane (IARC 1979). Because of chlordane's use as a soil-injected insecticide, and its persistence, it has the potential to contaminate groundwater, particularly when it is applied near existing wells (EPA 1988).

In soils, chlordane is comparatively immobile and persistent and has only a limited capacity for translocation into edible portions of food crops (NRCC 1975). Total chlordane content in cropland soils nationwide in 1971-72 averaged 0.05 to 0.06 mg/kg dry weight, and ranged between 0.01 and 7.9 mg/kg dry weight (Table 1); maximum values, in excess of 3.0 mg/kg, were recorded in soils from Illinois (7.0), Ohio (5.0), Indiana (4.1), and Iowa (Carey et al. 1978, 1979). The half-life of chlordane in soil when used at agricultural rates is about 1 year (IARC 1979), but residues may be measurable much longer, depending on soil type (NRCC 1975). For example, 10 years after application of 8.5 kg technical chlordane per hectare, up to 20% of the active ingredients were still measurable; in another study, 15 % of the active ingredients remained in turf soils after 15 years (WHO 1984). *Cis*- and *trans*-chlordanes were less persistent in mineral soils than in organic mucky soils (WHO 1984). Chlordanes were usually detected in surface soils of basins receiving urban runoff water at a maximum concentration of 2.7 mg/kg; this decreased with soil depth to <0.03 mg/kg at depths below 24 cm (Nightingale 1987). Chlordane levels in soils near Air Force bases in the United States in 1975-76 were similar to those found in nonmilitary urban environments (Lang et al. 1979).

Chlordanes in sediments usually were highest in those sediments with the highest organic content, especially downstream from the center of anthropogenic activities (Smith et al. 1987). Sediments from a lake in which the overlying water column initially was treated to contain 10 µg technical chlordane per liter contained measurable residues 2.8 years after application: total chlordanes--consisting of *cis*-chlordane, *trans*-chlordane, and *trans*-nonachlor--averaged 20 µg/kg and ranged up to 46 µg/kg (Albright et al. 1980). The yearly flux of chlordanes from sediments to the overlying water column has been estimated at 0.02 µg/m^2, based on measurements made in the Sargasso Sea and deep North Atlantic Ocean between 1978 and 1980 (Knap et al. 1986).

Terrestrial Crops

Maximum total chlordane concentrations in corn (*Zea mays*) and sorghum (*Sorghum halepense*) samples collected nationwide in 1971, in µ/kg dry weight, were 480 in corn kernel, 1,260 in cornstalk, and 420 in sorghum (Carey et al. 1978); these values were somewhat lower in 1972: 150 in kernels, 410 in stalks, and 150 in sorghum (Carey et al. 1979). Concentrations in various crops grown in soils treated with 15 kg technical chlordane per hectare were always <260 µg/kg dry weight when clay content was 12 %, and < 150 µg/kg when clay content was 28% (WHO 1984).

Table 1. Chlordane concentration in selected nonbiological samples.

Sample, units of measurement, chlordane Isomer, and other variables	Concentration[a]	Reference[b]
Air, in ng/m^3		
Between Bermuda and Rhode Island, February–		
June 1973, total chlordanes	(<0.005–0.9)	1
United States, 16 States		
2,477 of 2,479 samples	ND	2
2 samples	84,204	2
Southern Hemisphere, 1980–84, various locations,		
total chlordanes	(0.005–0.19)	3
Northern Hemisphere, 1973–78, Atlantic Ocean,		
total chlordanes	(0.009–0.084)	3
Pacific Ocean, 1979–81, total chlordanes	0.013	3
Canadian Arctic, summer 1984		
cis-chlordane	~0.0015	4
trans-chlordane	(0.0005–0.002)	4
cis-nonachlor	(ND to 0.0004)	4
trans-nonachlor	~0.0012	4
Fresh water, in ug/L		
Nova Scotia		
cis-chlordane	(ND to 31.3)	1

trans-chlordane	(ND to 17.9)	1
Ontario, Canada		
trans-chlordane	(<0.001–0.021)	1
Lower Mississippi River		
trans-chlordane	(0.0004–0.0012)	1
Iraq, Tigris-Euphrates Delta, 1986		
cis-chlordane	0.057, Max. 0.067	5
trans-chlordane	0.015, Max. 0.021	5
Urban runoff	0.1, Max. 0.3	6
Lake water, total chlordanes		
Start (treated)	10.0	7
Day 421 after treatment	(0.008–0.011)	7
Seawater, in ug/L		
Northern Pacific Ocean and Bering Sea, 1980–82		
cis-chlordane	(0.004–0.005)	8
trans-chlordane	(0.004–0.005)	8
cis-nonachlor	<0.0002	8
trans-nonachlor	(0.0013–0.0015)	8
oxychlordane	<0.0002	8
Sargasso Sea		
cis-chlordane	<0.001	8
trans-chlordane	<0.001	8
Tokyo Bay, Japan, total chlordanes	~0.002	8
Soils, in mg/kg dry weight		
Everglades National Park, Florida, 1976, total chlordanes		
In National Park	Max. 0.005	9
Adjacent agricultural area	Max. 0.195	9
United States, total chlordanes		
Croplands		
1970	0.08 (0.01–13.3)	10
1971	0.06 (0.01–7.0)	11
1972	0.05 (0.01–7.9)	12
35 States	(0.01–13.3)	1
Urban areas		
8 cities	(0.02–20.5)	1
14 cities	(0.04–13.9)	1
Near U.S. military bases, 1975–76, upper 7.6 cm		
Residential areas		
1975	5.4 (ND to 52.1)	13
1976	0.2 (ND to 1.2)	13

Nonuse areas		
1975	0.09 (ND to 1.8)	13
1976	0.2 (ND to 3.4)	13
Golf course		
1975	0.7 (ND to 4.6)	13
1976	0.6 (ND to 3.1)	13
Sediments, in ug/kg		
Total chlordanes		
Lake Superior, 1973	ND	14
Long Island, New York	Usually 20–200, Max. 580	15
Streams tributary to San Francisco Bay	(4–8)	1
Upper Rockaway River, New Jersey	(<1–510)	16
Hawaiian marina		
cis-chlordane	3.0 (0.4–5.3)	1
trans-chlordane	2.3 (1.3–5.1)	1
Bottom muds, Ontario, Canada		
trans-chlordane	<0.1–3.1	1
Stream beds, drainage ditches, Nova Scotia		
cis-chlordane	(0–664)	1
trans-chlordane	(0-51)	1

[a]Concentrations are shown as mean, extremes in parentheses, maximum (Max.), and nondetectable (ND).
[b]1, IARC 1979; 2, EPA 1980; 3, Kawano et al. 1985; 4, Hoff and Chan 1986; 5, DouAbul et al. 1988; 6, Nightingale 1987; 7, Albright et al. 1980; 8, Kawano et al. 1988; 9, Requejo et al. 1979; 10, WHO 1984; 11, Carey et al. 1978; 12, Carey et al. 1979; 13, Lang et al. 1979; 14, Frank et al. 1980; 15, Wood et al. 1986; 16, Smith et al. 1987.

Aquatic Invertebrates

Extremely high levels of chlordanes (e.g., 1,746 to 7,643 µg/kg FW) were measured in several species of south Florida corals collected in 1985 (Table 2). Researchers speculate that the elevated levels were because of the illegal disposal of chlordanes off Key Largo, Florida, in 1982 (Glynn et al. 1989).

Maximum concentrations of chlordanes in American oysters (*Crassostrea virginica*) taken in the Gulf of Mexico in 1976 were near 0.1 µg/kg dry weight (Table 2). Chlordane concentrations were substantially lower than concentrations of other organochlorines measured in oysters, such as DDT (28 µ/kg) and polychlorinated biphenyls (90 µg/kg), suggesting a need for additional studies on interaction effects of chlordane residues with those of other environmental chemicals (Rosales et al. 1979).

Marine clams and worms tended to underrepresent chlordane concentrations in the ambient sediments; concentration factors were less than 0.2 for clams and 0.6 for worms (Ray et al. 1983). Similarly, chlordane concentrations in clams from the Shatt al-Arab River in Iraq closely reflected chlordane concentrations in water particulates when compared to levels in water columns or in sediments (DouAbul et al. 1988).

Table 2. Chlordane concentrations in field collections of selected animals. Values shown are in micrograms per kg (parts per billion) fresh weight (FW), dry weight (DW), or lipid weight (LW).

Taxonomic group, organism, chlordane isomer, and other variables	Concentrationa (ug/kg)	Reference[b]
Aquatic invertebrates		
Bivalve mollusks, 3 species, Ebro River, Spain, 1980, soft parts		
Total chlordanes	(<1–21) DW	1
Corals, 10 species, Biscayne National Park, near Miami, Florida, July–September 1985, *cis*-chlordane and *trans*-chlordane		
Scleractinian corals		
Colpophyllia amaranthus	Max. 6 FW	84
Colpophyllia natans	Max. 62 FW	84
Diploria clivosa	Max. 32 FW	84
Diploria strigosa	Max. 6 FW	84
Montastrea annularis	Max. 1,746 FW	84
Porites asteroides	Max. 2,256 FW	84
Siderastrea sierea	Max. 145 FW	84
Octacorals		
Briareum abestinum	Max. 1,180 FW	84
Gorgonia flabellum	Max. 6,626 FW	84
Pseudopterogorgia acerosa	Max. 7,643 FW	84
Asiatic clam, *Corbicula fluminea*, Iraq, 1986, soft parts		
cis-chlordane	6 FW; Max. 10 FW	2
trans-chlordane	5 FW; Max. 9 FW	2
American oyster, *Crassostrea virginica*, Gulf of Mexico, Mexico, summer, 1976, soft parts		
cis-chlordane	Max. 0.1 DW	3
Krill, *Euphausia superba*, Antarctic Ocean, 1980–82, whole		
cis-chlordane	0.58 LW	4
trans-chlordane	0.51 LW	4
cis-nonachlor	0.22 LW	4
trans-nonachlor	0.8 LW	4
oxychlordane	0.1 LW	4
Eight-armed squid, *Gonatopsis borealis*, North Pacific Ocean, 1980–82 whole		
cis-chlordane	15 (11–18) LW	4
trans-chlordane	8.1 (6.3–9.9) LW	4
cis-nonachlor	2.4 (2.2–2.8) LW	4
trans-nonachlor	18 (14–20) LW	4

oxychlordane	1.2 (0.8–1.6) LW	4
total chlordanes	44 (35–52) LW	5
American lobster, *Homarus americanus*, east coast of Canada, 1971–77, hepatopancreas		
cis- and *trans*-chlordane	80–100 LW	6
cis-nonachlor	30 LW	6
trans-nonachlor	(380–440) LW	6
Mysid shrimp, *Mysis relicta*, Lake Michigan, 1980–81, whole		
July		
cis-chlordane	Max. 35 DW	7
trans-chlordane	Max. 44 DW	7
October		
cis-chlordane	ND	7
trans-chlordane	(72–151) DW	7
Sandworm, *Neanthes* sp., Portland, Maine, 1980, whole		
Total chlordanes	Max. 5.4 FW	8
Oysters, Hawaii, soft parts		
cis-chlordane	13 (1.6–58) FW	9
trans-chlordane	8 (1.4–23) FW	9
Amphipod, *Pontoporeia hoyi*, Lake Michigan, 1980–81, whole		
cis-chlordane	Max. 68 DW	7
trans-chlordane	Max. 184 DW	7
Crawfish, *Procambarus clarkii*, Louisiana, 1978–79, whole		
cis-chlordane	Max. 20 FW	10
trans-chlordane	Max. 26 FW	10
Short-necked clam, *Tapes philippinarum*, Tokyo Bay, Japan, 1978		
Muscle		
cis-chlordane	5.1 FW	11
trans-chlordane	2.3 FW	11
cis-nonachlor	0.7 FW	11
trans-nonachlor	1.3 FW	11
oxychlordane	0.2 FW	11
total chlordanes	40.6 FW	11
Viscera		
cis-chlordane	19.0 FW	11
trans-chlordane	11.0 FW	11
cis-nonachlor	3.1 FW	11
trans-nonachlor	7.9 FW	11
oxychlordane	0.2 FW	11
total chlordanes	40.6 FW	
Soft parts		
cis-chlordane	10.0 FW	11

trans-chlordane	5.7 FW	11
cis-nonachlor	3.7 FW	11
trans-nonachor	4.4 FW	11
oxychlordane	0.3 FW	11
total chlordanes	21.0 FW	11
Zooplankton, North Pacific Ocean, 1980–82, whole		
cis-chlordane	19 (13–27) LW	4
trans-chlordane	13 (7–20) LW	4
cis-nonachlor	5 (3.2–8.7) LW	4
trans-nonachlor	14 (12–15) LW	4
oxychlordane	3 (2.3–3.8) LW	4
total chlordanes	54 (40–72) LW	5
Fish		
Goby, *Acanthogobius flavimanus*, Tokyo Bay, Japan, 1978 whole		
cis-chlordane	6 FW; Max. 62 FW	11, 12
trans-chlordane	9 FW; Max. 15 FW	11, 12
cis-nonachlor	8 FW; Max. 21 FW	11, 12
trans-nonachlor	18 FW; Max. 120 FW	11, 12
oxychlordane	3 FW; Max. 25 FW	11, 12
White shark, *Carcharodon carcharius*, liver, east coast of Canada, 1971		
cis- and *trans*-chlordanes	2,600 LW	6
cis-nonachlor	1,700 LW	6
trans-nonachlor	8,500 LW	6
Baltic herring, *Clupea harengus*, Baltic Sea, 1978–82, whole		
Total chlordanes		
1978	(200–600) LW	13
1982	(400–800) LW	13
Atlantic herring, *Clupea harengus harengus*, oil, east coast of Canada, 1977		
cis- and *trans*-chlordanes	(40–110) LW	6
cis-nonachlor	Max. 30 LW	6
trans-nonachlor	Max. 170 LW	6
Lake whitefish, *Coregonus clupeaformis*		
Great Lakes, 1978, whole		
cis-chlordane	(16–94) FW	14
trans-chlordane	(21–87) FW	14
total chlordanes	111 FW	14
Lake Superior, Siskiwit Lake, Isle Royale, 1983, whole		
chlordanes	260 LW; Max. 330 LW	15
nonachlors	450 LW; Max. 500 LW	15
oxychlordane	16 LW; Max. 200 LW	15

Common carp, *Cyprinus carpio*		
Great Lakes, 1979, whole		
cis-chlordane	Max. 390 FW	16
trans-chlordane	Max. 360 FW	16
cis-nonachlor	Max. 390 FW	16
trans-nonachlor	Max. 300 FW	16
San Joaquin River, California, 1981, whole		
Total chlordanes	Max. 273 FW; Max. 3,578 LW	17
Shad, *Dorosoma* spp., Louisiana, 1978–79, whole body		
cis-chlordane	Max. 76 FW	10
trans-chlordane	Max. 82 FW	10
cis-nonachlor	Max. 26 FW	10
trans-nonachlor	Max. 12 FW	10
Northern pike, *Esox lucius*, Baltic Sea, 1971–82		
Total chlordanes		
Muscle		
1971	(100–1,000) LW	13
1972	(100–1,300) LW	13
1973	100 LW	13
1974	800 LW	13
1975	1,900 LW	13
1978	(2,600–3,100) LW	13
1982	(2,300–6,300) LW	13
Liver		
1971	(100–400) LW	13
1972	(100–300) LW	13
1973	500 LW	13
1974	600 LW	13
1975	700 LW	13
1978	700 LW	13
1982	(1,100–2,100) LW	13
Fish, 2 species, muscle, Belmont Lake, Long Island, New York		
Total chlordanes	380–5,200 FW	18
Fish, 4 species, Chesapeake Bay, Maryland, 1976–80		
Total chlordanes		
Muscle	70–120 FW; Max. 310–700 FW	19
Gonad	(10–1,900) FW	19
Fish, 4 species, eastern Finland, 1979–82		
Liver		
cis-chlordane	(ND to 76) FW	20
trans-chlordane	(ND to 277) FW	20

trans-nonachlor	(ND to 20) FW	20
total chlordanes	Max. 320 FW; Max. 410 LW	21
Muscle		
cis-chlordane	(ND to 53) FW	20
trans-chlordane	(ND to 232) FW	20
trans-nonachlor	(ND to 20) FW	20
total chlordanes	Max. 1,770 LW	21
Fish, 11 species, Lake Texoma, Texas and Oklahoma, 1979		
Total chlordanes		
Whole fish	(ND to 24) FW	22
Fish, Mississippi River, 1984–86		
Total chlordanes		
Shovelnose sturgeon, *Scaphirhynchus platyrynchus*		
Muscle	325–2,285 FW	75
Eggs	163–1,926 FW	75
Common carp, muscle	55–556 FW	75
Channel catfish, *Ictalurus punctatus*, muscle	322 to 1,389 FW	75
Fish, Mississippi River, 1988, muscle		
Total chlordanes		
Channel catfish	Max. 853 FW	75
Common carp	Max. 614 FW	75
Freshwater drum, *Aplodinotus grunniens*	Max. 19 FW	75
Flathead catfish, *Pylodictis olivaris*	Max. 272 FW	75
River carpsucker, *Carpiodes carpio*	Max. 160 FW	75
Smallmouth buffalo, *Ictiobus bubalus*	Max. 200 FW	75
Sauger, *Stizosteiden canadense*	Max. 19 FW	75
Paddlefish, *Polyodon spathula*	Max. 93 FW	75
Blue catfish, *Ictalurus furcatus*	Max. 895 FW	75
Bigmouth buffalo, *Ictiobus cyprinellus*	Max. 360 FW	75
White bass, *Morone chrysops*	Max. 436 FW	75
Fish, Missouri River, 1984–86		
Total chlordanes, 3 locations		
Shovelnose sturgeon		
Muscle	146–860 FW	75
Eggs	921–6,735 FW	75
Channel catfish, muscle	205–777 FW	75
Common carp, muscle	118–548 FW	75
Fish, Missouri River, 1988, muscle		
Near Rockport, 6 species		
total chlordanes	Max. 438 FW	75
heptachlor epoxide	Max. 15 FW	75
heptachlor	ND	75

oxychlordane	Max. 11 FW	75
trans-chlordane	Max. 25 FW	75
cis-chlordane	Max. 24 FW	75
trans-nonachlor	Max. 51 FW	75
cis-nonachlor	Max. 25 FW	75
total chlordenes	Max. 4 FW	75
Above, Kansas City, 2 species		
total chlordanes	Max. 290 FW	75
heptachlor epoxide	Max. 39 FW	75
heptachlor	ND	75
oxychlordane	Max. 48 FW	75
trans-chlordane	Max. 20 FW	75
cis-chlordane	Max. 25 FW	75
trans-nonachlor	Max. 55 FW	75
cis-nonachlor	Max. 14 FW	75
total chlordenes	Max. 35 FW	75
Below Kansas City, 6 species		
total chlordanes	95–2,450 FW	75
heptachlor epoxide	3–24 FW	75
heptachlor	ND	75
trans-chlordane	4–266 FW	75
cis-chlordane	7–260 FW	75
trans-nonachlor	9–167 FW	75
cis-nonachlor	5–66 FW	75
total chlordenes	4–144 FW	75
Fish, various species, whole		
Wabash River, Indiana		
cis-chlordane	13 FW	16
trans-chlordane	9 FW	16
cis-nonachlor	5 FW	16
trans-nonachlor	20 FW	16
oxychlordane	<0.5 FW	16
Ashtabula River, Ohio, total chlordanes	<0.5 FW	16
Great Lakes area, 1978		
cis- and *trans*-chlordanes	Max. 2,680 FW	23
cis- and *trans*-nonachlors	Max. 3,070 FW	23
oxychlordane	Max. 167 FW	23
Fish, United States, nationwide, 1976–84, whole		
cis-chlordane		
1976–77	60 FW; Max. 930 FW; 600 LW	24, 76
1978–79	70 FW; Max. 2,530 FW; 700 LW	24, 76

1980–81	30 FW; Max. 360 FW; 300 LW	24, 76
1984	30 FW; Max. 660 FW	76
trans-chlordane		
1976–77	20 FW; Max. 320 FW; 300 LW	24, 76
1978–79	20 FW; Max. Max. 540 FW; 300 LW	24, 76
1980–81	20 FW; Max. 220 FW; 200 LW	24, 76
1984	20 FW; Max. 350 FW	76
cis-nonachlor		
1976–77	10 FW; Max. 490 FW; 100 LW	24, 76
1978–79	30 FW; Max. 710 FW; 300 LW	24, 76
1980–81	20 FW; Max. 270 FW; 300 LW	24, 76
1984	20 FW; Max. 450 FW	76
trans-nonachlor		
1976–77	30 FW; Max. 950 FW; 300 LW	24, 76
1978–79	50 FW; Max. 2,710 FW; 600 LW	24, 76
1980–81	40 FW; Max. 770 FW; 100 LW	24, 76
1984	30 FW; Max. 1,000 FW	76
oxychlordane		
1978–79	10 FW; Max. 740 FW; 100 LW	24, 76
1980–81	10 FW; Max. 330 FW; 100 LW	24, 76
1984	10 FW; Max. 290 FW	76
heptachlor epoxide		
1976–77	10 FW; Max. 780 FW	76
1978–79	20 FW; Max. 1,170 FW	76
1980–81	10 FW; Max. 270 FW	76
1984	10 FW; Max. 290 FW	76
Atlantic cod, *Gadus morhua*		
East coast Canada, 1977, liver		
cis- and *trans*-chlordanes	ND	6
cis-nonachlor	70 LW	6
trans-nonachlor	(60–1,900) LW	6

Northern Baltic Sea, liver		
cis- and *trans*-chlordanes	Max. 50 LW	25
Shad, *Konosirus punctatus*, Tokyo Bay, Japan, 1979		
Total chlordanes		
Muscle	Max. 41 FW	11
Viscera	Max. 95 FW	11
Sea bass, *Lateolabrax japonicus*, Tokyo Bay, Japan, 1979		
Total chlordanes		
Gill	11 FW	11
Muscle	5 FW	11
Brain	41 FW	11
Kidney	37 FW	11
Liver	81 FW	11
Abdominal fat	279 FW	11
Bluegill, *Lepomis macrochirus*, San Joaquin River, California, whole fish, 1981		
Total chlordanes	Max. 14 FW; Max. 759 LW	17
Fourhorn sculpin, *Myoxocephalus quadricornis*, Lake Michigan, 1980–81, whole		
cis-chlordane	Max. 15 DW	7
trans-chlordane	Max. 70 DW	7
Cutthroat trout, *Oncorhynchus clarki*, liver, from lake sprayed with 10 µg technical chlordane per liter		
Total chlordanes		
Time, after application		
13.3 weeks	Max. 46,449 LW	26
39.8 weeks	Max. 3,940 LW	26
1.15 years	Max. 870 LW	26
2.78 years	ND	26
Chum salmon, *Oncorhynchus keta*, North Pacific Ocean, 1980–81, whole		
cis-chlordane	9 (8–11) LW	4
trans-chlordane	5.2 (5.1–5.9) LW	4
cis-nonachlor	2 (1.6–2.7) LW	4
trans-nonachlor	17 (13–21) LW	4
oxychlordane	2.5 (2.4–2.6) LW	4
total chlordanes	36 LW	5
Sea lamprey, *Petrolmyzon marinus*, Great Lakes, 1978, whole		
cis-chlordane	(9–202) FW	14
trans-chlordane	(3–243) FW	14
total chlordanes	88 FW	14
Lizard goby, *Rhinogobius flumineus*, Nagaragawa River, Japan, whole fish		

Total chlordanes		
1968–74	(ND to 7.6) FW	85
1977–86	(13–40) FW	85
Atlantic salmon, *Salmo salar*, east coast of Canada, 1976		
Egg		
cis- and *trans*-chlordanes	150 LW	6
cis-nonachlor	60 LW	6
trans-nonachlor	(130–210) LW	27
Lake trout, *Salvelinus namaycush*, Great Lakes, 1977–82, whole fish, oxychlordane		
Lake Michigan		
1977	250 FW	28
1978	180 FW	28
1979	240 FW	28
1980	160 FW	28
1981	60 FW	28
1982	70 FW	28
Lake Huron		
1978	40 FW	28
1979	60 FW	28
1980	60 FW	28
1981	60 FW	28
1982	60 FW	28
Lake Superior		
1977	120 FW	28
1978	40 FW	28
1979	140 FW	28
1980	30 FW	28
1981	60 FW	28
1982	40 FW	28
Great Lakes, 1979, whole		
cis-chlordane	Max. 25 FW	18
trans-chlordane	Max. 75 FW	18
cis-nonachlor	Max. 160 FW	18
trans-nonachlor	Max. 42 FW	18
Great Lakes, Lake Superior, Siskiwit Lake, Isle Royale, 1983, whole		
chlordanes	420 LW; Max. 770 LW	15
nonachlors	570 LW; Max. 1,100 LW	15
oxychlordane	73 LW; Max. 170 LW	15
Shovelnose sturgeon		
Muscle, Mississippi River, 1988		
total chlordanes	Max. 1,025 FW	75

heptachlor epoxide	Max. 31 FW	75
heptachlor	Max. 3 FW	75
oxychlordane	Max. 42 FW	75
trans-chlordane	Max. 75 FW	75
cis-chordane	Max. 90 FW	75
trans-nonachlor	Max. 95 FW	75
cis-nonachlor	Max. 65 FW	75
Eggs		
total chlordanes	Max. 1,484 FW	75
heptachlor epoxide	Max. 51 FW	75
heptachlor	Max. 5 FW	75
oxychlordane	Max. 56 FW	75
trans-chlordane	Max. 123 FW	75
cis-chlordane	Max. 148 FW	75
trans-nonachlor	Max. 146 FW	75
cis-nonachlor	Max. 90 FW	75
Walleye pollock, *Terhagra chalcogramma*, North Pacific Ocean, 1980–82, whole		
cis-chlordane	44 (34–54) LW	4
trans-chlordane	17 (16–20) LW	4
cis-nonachlor	10 (6–12) LW	4
trans-nonachlor	62 (47–92) LW	4
oxychlordane	8 (5–11) LW	4
total chlordanes	140 (110–190) LW	5
Benthic fish, *Trematomus bernacchii*, Antarctic Ocean, 1980–82, whole		
cis-chlordane	4 (2–8) LW	4
trans-chlordane	1.7 (0.8–3.4) LW	4
cis-nonachlor	3 (0.8–7) LW	4
trans-nonachlor	11 (2–29) LW	4
oxychlordane	1 (0.2–1.8) LW	4
Amphibians		
Frogs, *Rana* spp., Louisiana, 1978–79, chlordanes, muscle, whole body	ND	10
California newt, *Taricha torosa*, liver, from lake sprayed with 10 µg technical chlordane per liter		
Total chlordanes		
Time, after application		
14 days	Max. 34, 094 LW	26
9.3 months	Max. 10,094 LW	26
1.24 years	Max. 4,882 LW	26
2.84 years	Max. 601 LW	26
Reptiles		

American crocodile, *Crocodylus acutus*, infertile eggs		
cis-chlordane	Max. 10 FW	29
cis-nonachlor	Max. 30 FW	29
trans-nonachlor	Max. 40 FW	29
oxychlordane	Max. 70 FW	29
Northern water snake, *Nerodia sipedon*, Lake Michigan, 1978, chlordanes		
All tissues, stomach contents	ND	30
Common garter snake, *Thamnophis sirtalis*, Lake Michigan, 1978, *trans*-nonachlor		
Carcass	(100–250) FW	30
Stomach contents	ND	30
Other chlordane isomers	ND	30
Birds		
Mallard, *Anas platyrhynchos*, wing, nationwide		
1976–77		
Chlordane isomers		
Atlantic Flyway	(10–60) FW	31
Mississippi Flyway	(10–20) FW	31
Central Flyway	(10–20) FW	31
Pacific Flyway	(10–20) FW	31
1981–82		
cis-chlordane	Max. 20 FW	32
trans-nonachlor	Max. 50 FW	32
American black duck, *Anas rubripes*, chlordane isomers		
Atlantic Flyway, 1978, egg		
Maryland	50 FW	33
Massachusetts	80 FW	33
Maine	120 FW	33
New Hampshire	(130–160) FW	33
Atlantic Flyway, 1976–77, wing	10–50 FW	31
Great blue heron, *Ardea herodias*, northwestern United States, 1977–82		
Egg		
oxychlordane	Max. 570 FW	78
heptachlor epoxide	Max. 460 FW	78
cis-chlordane	Max. 1,360 FW	78
cis-nonachlor	Max. 690 FW	78
trans-nonachlor	Max. 2,250 FW	78
Whole body, oxychlordane	Max. 470 FW	78
Brain, oxychlordane	Max. 230 FW	78
Canvasback, *Aythya valisineria*		
Egg, breeding areas, 1972–73		

cis-chlordane	<1,000 FW	34
cis-nonachlor	ND	34
oxychlordane	<1,000 FW	34
Carcass (less GI tract, skin, feet, beak) Chesapeake Bay, Maryland, winter		
cis-chlordane		
1973	ND	35
1975	9,000 FW	35
trans-nonachlor		
1973	ND	35
1975	11,000 FW	35
oxychlordane		
1973	ND	35
1975	5,000 FW	35
Birds, 4 species, eastern and southern United States, 1972–74, egg, total chlordanes	<100 FW	36
Birds, New York State, 1982–86, found dead or debilitated, brain tissue, chlordane implicated as primary cause of distress		
Cooper's hawk, *Accipiter cooperii*		
oxychlordane	Max. 5,800 FW	79
heptachlor epoxide	Max. 4,300 FW	79
trans-nonachlor	Max. 1,300 FW	79
Sharp-shinned hawk, *Accipiter striatus*		
oxychlordane	Max. 4,300 FW	79
heptachlor epoxide	Max. 3,500 FW	79
trans-nonachlor	Max. 1,000 FW	79
Great blue heron		
oxychlordane	Max. 2,400 FW	79
heptachlor epoxide	Max. 600 FW	79
Great horned owl, *Bubo virginianus*		
oxychlordane	Max. 8,700 FW	79
heptachlor epoxide	Max. 7,700 FW	79
trans-nonachlor	Max. 2,300 FW	79
Blue jay, *Cyanocitta cristata*		
oxychlordane	Max. 5,000 FW	79
heptachlor epoxide	Max. 3,700 FW	79
trans-nonachlor	Max. 2,000 FW	79
Eastern screech owl, *Otus asio*		
oxychlordane	Max. 2,600 FW	79
heptachlor epoxide	Max. 1,800 FW	79
trans-nonachlor	Max. 1,800 FW	79
Common grackle, *Quiscalus quiscula*		

oxychlordane	Max. 10,800 FW	79
heptachlor epoxide	Max. 9,100 FW	79
Eastern bluebird, *Sialia sialis*		
oxychlordane	Max. 3,000 FW	79
heptachlor epoxide	Max. 2,200 FW	79
European starling, *Sturnus vulgaris*		
oxychlordane	Max. 7,700 FW	79
heptachlor epoxide	Max. 5,000 FW	79
trans-nonachlor	Max. 500 FW	79
American robin, *Turdus migratorius*		
oxychlordane	Max. 1,300 FW	79
heptachlor epoxide	Max. 2,700 FW	79
trans-nonachlor	Max. 1,900 FW	79
Cackling Canada goose, *Branta canadensis minima*, 1973–74, carcass, breeding areas, total chlordanes		
Uncontaminated	<1 FW	37
Contaminated (Oregon, California)		
Immature male	<0.2 FW	37
Adult male	1.7 FW	37
Adult female	2.0 FW	37
Common goldeneye, *Bucephala clangula*, fat, oxychlordane		
On arrival at wintering grounds, New York		
Juveniles	40 (10–300) LW	38
Adults	220 (120–370) LW	38
Just before to spring migration		
Adults	250 (190–320) LW	38
Dunlin, *Calidris alpina*, Washington State, 1980, whole		
Total chlordanes	Max. 60 FW	39
Peregrine, *Falco peregrinus*, Alaska, 1979–84, egg		
trans-nonachlor	Max. 290 FW	40
oxychlordane	130 FW; Max. 960 FW	40
Atlantic puffin, *Fratercula arctica*, Hornoy, Norway, 1982–83, oxychlordane plus *trans*-nonachlor		
Adults		
Uropygial gland	1,429 (48–2,815) LW	41
Liver	93 (262–1,531) LW	41
Chicks		
Brain	833 (445–1,289) LW	41
Chicken, *Gallus* sp., contaminated through use of former chlordane container to hold cage disinfectants, Australia		
Egg	300 DW	42
Pullets, fat		
30 weeks old	920 DW	42

80 weeks old	670 DW	42
Nationwide, egg		
cis-chlordane	1 FW	9
trans-chlordane	2 FW	9
Gull-billed tern, *Sterna nilotica*, South Carolina, 1972–75		
Egg		
Oxychlordane	Max. 290 FW	80
trans-nonachlor	ND	80
Bald eagle, *Haliaeetus leucocephalus*		
Egg, total chlordanes		
Maryland, Virginia, 1980–84	1,100 FW	82
Maine, 1980–84	500 FW	82
Ohio, 1981–84	840 FW	82
Oregon, 1980–83	220 FW	82
Arizona, 1982–84	160 FW	82
Wisconsin, 1980–83	330 FW	82
Nationwide, found dead or moribund		
1971–74		
Brain		
cis-chlordane plus *trans*-chlordane	270 FW	43
cis-nonachlor	290 FW	43
oxychlordane	150 FW	43
Carcass (less skin, beak, feet, GI tract, liver)		
cis-chlordane plus *trans*-chlordane	27,000 LW	43
cis-nonachlor	30,000 LW	43
oxychlordane	15,000 LW	43
1975–77		
Brain		
cis-chlordane	90–190 FW; Max. 6,400 FW	44
cis-nonachlor	130–170 FW; Max. 750 FW	44
trans-nonachlor	200–330 FW; Max. 7,400 FW	44
oxychlordane	180–290 FW; Max. 2,600 FW	44
Carcass (less skin, viscera)		
cis-chlordane	220–320 FW; Max. 4,500 FW	44
cis-nonachlor	100–150 FW; Max. 1,700 FW	44
trans-nonachlor	280–380 FW; Max. 6,000 FW	44
oxychlordane	130–180 FW; Max. 2,300 FW	44
1978–81		
Brain		
cis-chlordane	90–190 FW; Max. 2,300 FW	45
cis-nonachlor	100–230 FW; Max. 1,600 FW	45
trans-nonachlor	180–410 FW; Max. 4,100 FW	45
oxychlordane	120–260 FW; Max. 2,700 FW	45

Carcass (less skin, viscera)		
cis-chlordane	120–290 FW; Max. 2,200 FW	45
cis-nonachlor	120–190 FW; Max. 1,200 FW	45
trans-nonachlor	230–370 FW; Max. 4,100 FW	45
oxychlordane	90–130 FW; Max. 1,450 FW	45
Herring gull, *Larus argentatus*		
Egg, Canada, 1973		
cis- and *trans*-chlordanes	220 LW	6
cis-nonachlor	20 LW	6
trans-nonachlor	520 LW	6
Egg, Maine, 1977		
trans-nonachlor	50 (ND to 500) FW	46
Egg, Virginia, 1977		
trans-nonachlor	40 (ND to 440) FW	46
oxychlordane	20 (ND to 180) FW	46
Chicks, age 21 days		
Liver, oxychlordane	6 (2–13) FW	47
Muscle, oxychlordane	4–140 FW	47
Glaucous-winged gull, *Larus glaucescens*, Alaska, 1973–76		
Egg		
cis-chlordane	Max. 75 FW	48
cis-nonachlor	Max. 26 FW	48
oxychlordane	Max. 250 FW	48
Great black-backed bull, *Larus marinus,* Maine, 1977		
Egg		
cis-chlordane	40 (ND to 500) FW	46
oxychlordane	220 (ND to 430) FW	46
Red breasted merganser, *Mergus serrator*, Lake Michigan, United States, 1978, carcass		
trans-nonachlor	Max. 480 FW	30
Long-billed curlew, *Numenius americanus*, Oregon, 1981–83, convulsions noted, brain		
cis-chlordane	(110–300) FW	49
trans-chlordane	(ND to 50) FW	49
cis-nonachlor	(ND to 470) FW	49
trans-nonachlor	(140 –4,100) FW	49
oxychlordane	(2,500–4,400) FW	49
heptachlor epoxide	(1,000–4,800) FW	49
Yellow-crowned night-heron, *Nycticorax violaceus*, Louisiana, 1978–79, whole body		
Total chlordanes	ND	10
Osprey, *Pandion haliaetus*		
Eastern United States, 1975–82, dead or moribund, carcass		

(less skin, feet, and back)		
cis-chlordane	Max. 680 FW	50
cis-nonachlor	Max. 480 FW	50
trans-nonachlor	Max. 280 FW	50
oxychlordane	Max. 350 FW	50
Eagle Lake, California, 1973–84, egg		
cis-chlordane	Max. 10 FW	51
trans-nonachlor	Max. 6 FW	51
oxychlordane	Max. 6 FW	51
Fourteen states, United States, 1970–79, egg		
cis-chlordane	Usually <100; Max. 1,100	52
cis-nonachlor	Usually <100; Max. 400	52
trans-nonachlor	Usually <100; Max. 500	52
oxychlordane	Usually <100; Max. 400	52
Passeriformes, 38 species, western United States, 1980, carcass (less beak, feet, GI tract, feathers)		
oxychlordane	Usually <50 FW; Max. 290 FW	53
Brown pelican, *Pelecanus occidentalis*, South Carolina, 1974–75, egg		
oxychlordane	Max. 530 FW	81
heptachlor epoxide	Max. 500 FW	81
cis-chlordane	Max. 960 FW	81
trans-nonachlor	Max. 980 FW	81
cis-nonachlor	Max. 630 FW	81
Adelie penguin, *Pygoscelis adeliae*, Antarctic Ocean, 1980–82, subcutaneous fat		
cis-chlordane	0.9 LW	4
trans-chlordane	<0.05 LW	4
cis-nonachlor	1.7 LW	4
trans-nonachlor	15 LW	4
oxychlordane	16 LW	4
Black skimmer, *Rynchops niger*, South Carolina, 1972–75		
Egg		
oxychlordane	Max. 520 FW	80
trans-nonachlor	Max. 520 FW	80
Adults, found dead		
oxychlordane		
Brain	Max. 880 FW	80
Carcass	Max. 560 FW	80
cis-chlordane		
Brain	Max. 540 FW	80
Carcass	Max. 150 FW	80

Shorebirds, 7 species, Corpus Christi, Texas, winter 1976–77, skinned carcasses		
Total chlordanes	Usually <1,000 FW;	54
Max. 1,700 FW		
Forster's tern, *Sterna forsteri*, egg, Lake Michigan, 1983		
cis-chlordane	(<10–60) FW	77
trans-chlordane	(<10–20) FW	77
trans-nonachlor	(<10–170) FW	77
oxychlordane plus heptachlor epoxide	(10–230) FW	77
heptachlor	(10–300) FW	77
European starling, *Sturnus vulgaris*, whole (less beak, wing tip, feet, skin), nationwide		
1972		
oxychlordane	Max. 100 FW	55
1979		
total chlordanes	Max. 290 FW	56
1982		
cis-chlordane	Max. 30 FW	57
cis-noncachlor	Max. 70 FW	57
trans-nonachlor	Max. 40 FW	57
oxychlordane	Max. 140 FW	57
Northern gannet, *Sula bassanus*, eastern Canada, 1969–84		
Egg		
cis-chlordane		
1969	Max. 550 FW	58
1970	Max. 520 FW	58
1984	Max. 150 FW	58
cis-nonachlor		
1969	Max. 380 FW	58
1970	Max. 370 FW	58
1984	Max. 150 FW	58
oxychlordane		
1969	Max. 208 FW	58
1970	Max. 202 FW	58
1984	Max. <100 FW	58
Tree swallow, *Tachycineta bicolor*, Alberta, Canada, 1978–79		
Eggs and nestlings		
cis-chlordane	<30 FW	59
oxychlordane	<30 FW	59
Thick-billed murre, *Uria lomvia*, northern Pacific Ocean, 1980–82, subcutaneous fat		
cis-chlordane	3 (1.4–3.9) LW	4
trans-chlordane	<0.05 LW	4

cis-nonachlor	10 (3–15) LW	4
trans-nonachlor	3 (1.7–4.5) LW	4
oxychlordane	82 (63–130) LW	4
total chlordanes	98 (63–150) LW	4
Waterbirds, 3 species, Galveston Bay, Texas, 1980–82, total chlordanes		
Carcass (less skin, feet, bill, GI tract)	Max. 1,200 FW	60
Egg	Max. 900 FW	60
Mammals		
Bats, 3 species, Maryland and West Virginia, 1973, near high chlordane use area, oxychlordane		
Carcass	Max. 3,000 FW	61
Guano	Max. 100 FW	61
Cow, *Bos bovis*, milk, total chlordanes		
Nationwide	20–60 FW	9
Illinois, 1971–73	50 FW	62
Cattle, *Bos* sp., grazing heptachlor-contaminated pastures for 4 weeks (some deaths), oxychlordane, subcutaneous fat		
End of grazing	5,700 FW	63
48 days later	180 FW	63
Dog, *Canis familiaris*, Tokyo, 1979, adipose tissue		
trans-nonachlor	17 FW	11
oxychlordane	71 FW	11
total chlordanes	88 FW	11
Cat, *Felis domesticus*, Tokyo, 1979, adipose tissue		
cis-nonachlor	60 FW	11
trans-nonachlor	51 FW	11
oxychlordane	50 FW	11
total chlordanes	160 FW	11
Long-finned pilot whale, *Globicephala melaena*, Newfoundland, 1980, blubber		
Total chlordanes		
Males	1,600 (1,000–3,200) FW	64
Females	700 (200–1,900) FW	64
Grey seal, *Halichoerus grypus*, Gulf of Finland, 1976–82		
Blubber		
cis-chlordane	50 FW	65
trans-chlordane	130 FW	65
trans-nonachlor	700 FW	65
oxychlordane	210 FW	65
total chlordanes	970 FW	65
Human, *Homo sapiens*		
Mother's milk		

Hawaii, 1979		
trans-nonachlor	2.5 FW	66
oxychlordane	1.9 FW	66
Arkansas and Mississippi, 1973–74		
Total chlordanes	5 FW; Max. 20 FW	62
Japan, 1979		
cis-chlordane	0.1 FW	66
trans-chlordane	0.2 FW	66
cis-nonachlor	0.2 FW	66
trans-nonachlor	0.8 FW	66
oxychlordane	0.5 FW	66
Japan, 1983		
cis-chlordane	0.1 FW; 3.1 LW	67
trans-chlordane	0.04 FW; 1.2 LW	67
cis-nonachlor	0.1 FW; 4.0 LW	67
trans-nonachlor	0.5 FW; 15.7 LW	67
oxychlordane	0.4 FW; 11.5 LW	67
Finland, 1982		
cis-chlordane	<0.05 FW; <1.0 LW	66
trans-chlordane	<0.05 FW; <1.0 LW	66
cis-nonachlor	0.08 FW; 2.0 LW	66
trans-nonachlor	0.4 FW; 10.0 LW	66
oxychlordane	0.2 FW; 5.0 LW	66
Blood, Tokushima City, Japan		
cis-chlordane	0.05 FW; Max. 0.14 FW	68
trans-chlordane	0.1 FW; Max. 0.22 FW	68
cis-nonachlor	0.03 FW: Max. 0.08 FW	68
trans-nonachlor	0.08 FW; Max. 0.29 FW	68
oxychlordane	0.2 FW; Max. 0.75 FW	68
total chlordanes	0.51 FW; Max. 1.1 FW	68
Fat, worldwide, oxychlordane	140 (30–400) FW	69
White-beaked dolphin, *Lagenorhynchus albirostris*, Newfoundland, 1982, blubber		
Total chlordanes		
Males	12,700 (6,300–25,000) FW	64
Females	8,300 (3,700–15,000) FW	64
Weddell seal, *Leptonychotes weddelli*, Antarctic Ocean, 1980–82, blubber		
cis-chlordane	7 LW	4
trans-chlordane	<0.05 LW	4
cis-nonachlor	8 LW	4
trans-nonachlor	41 LW	4
oxychlordane	13 LW	4

River otter, *Lutra canadensis,* liver, Alberta, Canada, 1980–83		
cis-chlordane	Max. 6 FW	70
oxychlordane	Max. 13 FW	70
Gray bat, *Myotis grisescens*, Missouri, 1976–77, found dead		
Brain		
cis-chlordane	Max. 1,000 FW	71
trans-nonachlor	Max. 2,100 FW	71
oxychlordane	Max. 2,300 FW	71
Carcass		
cis-chlordane	6,300 (15,000–108,000) LW	71
trans-nonachlor	159,000 (91,000–252,000) LW	71
oxychlordane	68,000 (16,000–167,000) LW	71
Pacific walrus, *Odobenus rosmarus divergens*, oxychlordane, blubber		
Alaska, 1981–84	20–60 FW	83
Soviet Union, 1984	100 FW	83
Saimaa ringed seal, *Phoca hispida saimensis*, Finland, 1977–81		
Total chlordanes		
Blubber	590 (110–1,700) LW	72
Liver	200 (10–400) FW	72
Muscle	20 (10–30) FW	72
Harbor seal, *Phoca vitulina*, Netherlands, blubber		
trans-nonachlor	2,700 LW	73
oxychlordane	3,000 LW	73
Dall's porpoise, *Phocoenoides dalli*, North Pacific Ocean, 1980–82, blubber		
cis-chlordane	440 (360–550) LW	4
trans-chlordane	63 (53–73) LW	4
cis-nonachlor	270 (240–310) LW	4
trans-nonachlor	1,800 (1,600–2,000) LW	4
oxychlordane	250 (160–340) LW	4
total chlordanes	2,800 (2,700–3,000) LW	5
Raccoon, *Procyon lotor*, Louisiana, 1978–79, muscle		
cis-chlordane	17 FW	10
trans-chlordane	17 FW	10
Gray squirrel, *Sciurus carolinensis*, Jacksonville, Florida, 1974, fat		
nonachlors	Max. 110 LW	74
oxychlordane	Max. 62 LW	74

[a]Concentrations are shown as mean, extremes in parentheses, maximum (Max.), and nondetectable (ND).

[b]Risebrough et al. 1983; 2, DouAbul et al. 1988; 3, Rosales et al. 1979; 4, Kawano et al. 1988; 5, Kawano et al. 1986; 6, Zitko 1978; 7, Evans et al. 1982; 8, Ray et al. 1983; 9, IARC 1979; 10, Dowd et al. 1985; 11, Yamagishi et al. 1981; 12, Miyazaki et al. 1980; 13, Moilanen et al. 1982; 14, Kaiser 1982; 15, Swackhamer and Hites 1988; 16, Kuehl et al. 1980; 17, Saiki and Schmitt 1986; 18, Kuehl et al. 1983; 19, Eisenberg and Topping 1985; 20, Pyysalo et al. 1981; 21, Pyysalo et al. 1983; 22, Hunter et al. 1980; 23, veith et al. 1981; 24, Schmitt et al. 1985; 25, Wickstrom et al. 1981; 26, Albright et al. 1980; 27, Zitko and Saunders 1979; 28, DeVault et al. 1986; 29, Hall et al. 1979; 30, Heinz et al. 1980; 31, White 1979; 32, Prouty and Bunck 1986; 33, Haseltine et al. 1980; 34, Stendell et al. 1977; 35, White et al. 1979; 36, Klaas et al. 1980; 37, Anderson et al. 1984; 38, Foley and Batcheller 1988; 39, Schick et al. 1987; 40, Ambrose et al. 1988; 41, Ingebrigtsen et al. 1984; 42, Reece et al. 1985; 43, Barbehenn and Reichel 1981; 44, Kaiser et al. 1980; 45, Reichel et al. 1984; 46, Szaro et al. 1979; 47, Peakall et al. 1986; 48, Ohlendorf et al. 1982; 49, Blus et al. 1985; 50, Wiemeyer et al. 1987; 51, Littrell 1986; 52, Wiemeyer et al. 1988; 53, De Weese et al. 1986; 54, White et al. 1980; 55, Nickerson and Barbehenn 1975; 56, Cain and Bunck 1983; 57, Bunck et al. 1987; 58, Elliott et al. 1988; 59, Shaw 1984; 60, King and Krynitsky 1986; 61, Clark and Prouty 1976; 62, EPA 1980; 63, Petterson et al. 1988; 64, Muir et al. 1988; 65, Perttila et al. 1986; 66, Wickstrom et al. 1983; 67, Tojo et al. 1986; 68, Wariishi et al. 1986; 69, WHO 1984; 70, Somers et al. 1987; 71, Clark et al. 1980; 72, Helle et al. 1983; 73, Kerkhoff and Boer 1982; 74, Nalley et al. 1978; 75, Bush and Grace 1989; 76, Schmitt et al. 1990; 77, Kubiak et al. 1989; 78, Fitzner et al. 1988; 79, Stone and Okoniewski 1988; 80, Blus and Stafford 1980; 81, Blus et al. 1979; 82, S. Wiemeyer, Patuxent Wildlife Research Center, personal communication; 83, Taylor et al. 1989; 84, Glynn et al. 1989; 85, Loganathan et al. 1989.

Fishes

Health advisories have been issued near Lawrence Kansas, based on chlordane levels in edible fish tissues. In fish from the Kansas River, Kansas, in 1986, chlordanes were detected more frequently and at higher levels than other contaminants measured (Arruda et al. 1987). More than 80% of the sites sampled in Kansas had detectable chlordanes in fish; at more than 50% of these sites, levels exceeded 0.1 mg/kg fresh weight--a guideline for the protection of predatory fish. At three urban sites in Kansas, concentrations of chlordanes in fish have approached or exceeded the Food and Drug Administration action level of 0.3 mg chlordane per kilogram of fresh weight for protection of human health. The most likely source of chlordane in fish from the Kansas River is urban and suburban use of chlordane as a termite control agent (Arruda et al. 1987). Other health advisories based on chlordane contamination have been issued. In 1985, people were warned not to eat shovelnose sturgeon (*Scaphirhynchus platyrynchus*) from the Missouri and Mississippi rivers. In 1987, advisories warned against the consumption of sturgeon from the Missouri River between Kansas City and St. Louis, and against bullhead catfishes, suckers, carps, sturgeons, and sturgeon eggs from the Mississippi River near St. Louis (Bush and Grace 1989).

Chlordane residues were detected in 36% of all fish samples collected in major domestic watersheds in 1976 (Veith et al. 1979). In the Great Lakes region in 1979, chlordane residues in fish tissues exceeded 100 μ/kg on a fresh weight basis in about 40% of the samples measured; residues were highest in samples collected near Alton, Illinois, and Fairborn, Ohio (Kuehl et al. 1983).

The two most abundant components of technical chlordane found in fish tissues from Tokyo Bay, Japan, were *trans*-nonachlor and *cis*-chlordane (Yamagishi et al. 1981 b; Table 2). However, this may vary between locales. For example, *cis*-chlordane and *trans*-chlordane were the most abundant components in fish samples collected throughout Japan during the past 20 years, followed, in order, by *cis*-nonachlor, *trans*-nonachlor, and oxychlordane (Loganathan et al. 1989). Of the total chlordanes measured in muscle of northern pike *(Esox lucius)* from the Baltic Sea, 37% was *cis*-chlordane, 34% *trans*-chlordane, and 15% each *trans*-nonachlor and oxychlordane (*(Esox lucius)* and Baltic herring (Moilanen et al. 1982). For liver tissue of northern pike, 35 % was oxychlordane, 28% *trans*-chlordane, 22% *cis*-chlordane, and 14% *trans-non*achlor (*(Esox lucius)* and Baltic herring *(*Moilanen et al. 1982). In the United States, only chlordanes and nonachlors have been detected as significant residues in fish collected nationwide. The most abundant component was *cis*-chlordane, followed by *trans*-nonachlor, *trans*-chlordane, and *cis*-nonachlor (Ribick and Zajicek 1983). The two most abundant components were detected in about 93 % of all fish samples collected in 1978 and 1979; residues were usually highest in Hawaii, the Great Lakes, and the Corn Belt (Ribick and Zajicek 1983). Fish from Manoa Stream in Hawaii had high residues because of heavy use of technical chlordane in pineapple culture and termite control (Ribick and Zajicek 1983). Nationwide monitoring of freshwater fishes showed that chlordane concentrations in whole fish did not change from 1980 to 1994, following a period of decline; however, *trans*-nonachlor replaced *cis*-chlordane as the most abundant component, suggesting a lower influx of chlordane to the aquatic environment from terminated use of chlordane in agriculture in the mid- 1970's (Schmitt et al. 1990; Table 2). Residues of *cis*-chlordane and *trans*-nonachlor--the most abundant and persistent of the chlordane components measured --were present at 85 and 89% of the stations sampled in 1984 (Schmitt et al. 1990). Maximum chlordane levels in fish in 1984 occurred in the Great Lakes, Hawaii, watersheds of the Ohio, Missouri, and Mississippi rivers, and in the Delaware and Raritan rivers in the Northeast (Schmitt et al. 1990).

Atmospheric transport may be the main source of chlordane in Finland --a country that prohibits chlordane use— because chlordanes are distributed evenly in the Finnish environment (Pyysalo et al. 1983). No chlordane compounds were detected in rainbow trout (*Oncorhynchus mykiss*) taken from lakes in eastern Finland, although measurable residues were detected in other fish species. This phenomenon is attributed to the superior ability of rainbow trout to metabolize chlordanes to oxychlordane (Pyysalo et al. 1981).

Amphibians and Reptiles

Chlordane residue data for amphibians and reptiles are extremely limited. Maximum concentrations of chlordane isomers did not exceed 70 µg/kg FW of oxychlordane in eggs of the American crocodile, *Crocodylus acutus,* or 250 µg/kg FW in carcass of the common garter snake, *Thamnophis sirtalis* (Table 2). However, California newts, *Taricha torosa*, taken near a lake treated with 10 µg/L technical chlordane had greatly elevated chlordane residues in liver and comparatively low concentrations in carcass, stomach, and stomach contents. After 14 days, livers contained about 34 mg/kg total chlordanes lipid weight--about 19% chlordanes, 9% nonachlors, and 6% chlordanes (Albright et al. 1980). After 2.8 years, 98% of the total chlordanes was lost. *Trans*-nonachlor was the most persistent component in newt liver, accounting for up to 55% of the total chlordanes in specimens collected 2.8 years after application (Albright et al. 1980; Table 2).

Birds

Technical chlordane components and their metabolites--especially oxychlordane--are comparatively elevated in tissues with high lipid content, in older birds, and in raptors (Table 2).

Chlordane isomers occur frequently in birds collected nationwide. In 1976, for example, 41 % of European starlings (Cain and Bunck 1983). In 1982, oxychlordane was detected in 45 % of all starlings analyzed, *trans*-nonachlor in 40%, *cis*-nonachlor in 9%, and *cis*- and *trans*-chlordanes in fewer than 2% (Bunck et al. 1987). Chlordane isomers were detected at frequencies exceeding 50% in wings of American black ducks *(Anas rubripes)* and mallards *(Anas platyrhynchos)* from the Atlantic Flyway in 1976-77 (White 1979), in eggs of 19 species of Alaskan seabirds in 1973-76 (Ohlendorf et al. 1982), and in carcasses of ospreys (Pand*ion haliaetus)* found dead in the eastern United States between 1975 and 1982 (Wiemeyer et al. 1987). Frequency of detection for chlordane isomers ranging between 14 and 40% has been reported in wings of American black ducks and mallards from flyways other than the Atlantic Flyway (White 1979), in 19 species of passeriformes from the western United States in 1980 (DeWeese et al. 1976), and in 7 species of Texas shorebirds in 1976-77--although residues in shorebirds were below levels known to adversely affect reproduction or survival (White et al. 1980).

Carcasses of bald eagles (*Haliaeetus leucocephalus*) collected between 1978 and 1981 usually contained oxychlordane at 45 to 56% frequency, *trans*-nonachlor at 62 to 74%, *cis*-chlordane at 38 to 45%, and *cis*-nonachlor at 38 to 47%. Frequency of occurrence in the brain was lower, ranging between 19 and 55% for individual isomers (Reichel et al. 1984). However, a positive correlation was established in bald eagles between concentration of chlordanes in brain on a fresh weight basis and in carcass on a lipid weight basis; this relation seems to extend to other birds as well (Barbehenn and Reichel 1981). Bald eagles also contained appreciable quantities of other organochlorine compounds, and a few--for example, dieldrin--were sometimes present at concentrations considered life-threatening (Reichel et al. 1984). A similar situation exists in other species of raptors (Ambrose et al. 1988).

Some chlordane isomers tend to persist in avian tissues for lengthy periods. In northern gannets (*Sula bassanus*), the half-time persistence of *cis*-chlordane, *cis*-nonachlor, and oxychlordane was estimated at 11.2, 19.4, and 35.4 years (Elliott et al. 1988). Oxychlordane residues in the thick-billed murre *(Uria lomvia)* tend to be high because of rapid excretion through uropygial gland secretions of *cis*- and *trans*-chlordanes and nonachlors, and to biotransformation of these and other chlordane components to oxychlordane (Kawano et al. 1988). This observation is alarming because the metabolite oxychlordane has proven much more toxic and persistent than the parent chemicals (Kawano et al. 1988). Secondary poisonings of raptors after consumption of poisoned bait or prey that had accumulated a large quantity of chlordane were documented for the red-shouldered hawk *(Buteo lineatus)* and the great horned owl (*Bubo virginianus*); concentrations of oxychlordane and heptachlor epoxide found in brain and carcass of both species (Blus et al. 1983) were within the lethal range reported in experimental studies (Stickel et al. 1979).

Chlordane-induced mortality of the long-billed curlew *(Numenius americanus)* has been documented at least four times since 1978, despite restriction of technical chlordane use since 1980 to subterranean applications for termite control (Blus et al. 1985). Death of these curlews was probably due to over-winter accumulations of oxychlordane of 1.5 to 5.0 mg/kg brain FW and of heptachlor epoxide at 3.4 to 8.3 mg/kg--joint lethal ranges for oxychlordane and heptachlor epoxide in experimental birds— compared with 6 mg/kg brain for oxychlordane alone, and 9 mg/kg for heptachlor epoxide alone (Blus et al. 1985). Additional research is needed on toxic interactions of chlordane components with each other and with other chemicals in the same environment.

Mammals

Chlordane levels in mammals were usually highest in lipids, in animals collected near areas of high chlordane use, and in aquatic mammals, especially marine species (Table 2). Biomagnification of total chlordane through the food chain was strongly evident in marine mammals; chlordanes were concentrated gradually from zooplankton, through squid and fish, to porpoises and dolphins (Kawano et al. 1986; Muir et al. 1988; Table 2). Chlordane residues in marine mammals were positively related to lipid content and not to the age of the animal (Perttila et al. 1986).

A high death rate over a 2-year period was evident in the little brown bat (*Myotis lucifugus*) following application of chlordane; young bats were most affected in the first year after application and adults in the second year (Kunz et al. 1977). Residues were greatly elevated in the brain and carcass of another bat, the gray bat (*Myotis grisescens*)-an endangered species--found dead near areas of high chlordane use (Table 2).

Chlordane levels in human blood were comparatively elevated among individuals living in residences treated with chlordane during the past 5 years, and in termite control operators; oxychlordane levels were usually significantly higher than *trans*-nonachlor except among those who consumed large quantities of fish (Wariishi et al. 1986; Wariishi and Nishiyama 1989).

Lethal and Sublethal Effects

General

Chlordane has been applied extensively to control pestiferous soil invertebrates, usually at rates between 0.6 and 2.24 kg/ha; within this range sensitive nontarget species, especially earthworms, were adversely affected.

Nominal water concentrations between 0.2 and 3.0 µg/L were harmful to various species of fish and aquatic invertebrates. Effects included a reduction in survival, immobilization, impaired reproduction, histopathology, and elevated chlordane accumulations. *Cis*-chlordane, when compared with *trans*-chlordane, was more toxic, preferentially stored, and concentrated to a greater degree. In aquatic organisms, *cis*-chlordane photoisomers were frequently more toxic than the parent form. Oxychlordane was not a major metabolite in aquatic fauna.

Sensitive bird species had reduced survival after consumption of diets as low as 1.5 mg chlordane per kilogram of ration, or after a single oral dose as low as 14.1 mg/kg BW; accumulations were documented in tissues following consumption of diets containing 0. 1 to 0.3 mg chlordane per kilogram of feed. Oxychlordane was the most persistent metabolite in avian brain tissue.

Concern for the continued widespread use of chlordane centers on its ability to cause liver cancer in domestic mice. Other adverse effects in mammals, such as elevated tissue residues and growth inhibition, were frequently associated with diets containing between 0.76 and 5.0 mg chlordane per kilogram of feed. Metabolism of technical chlordane by mammals results primarily in oxychlordane, a metabolite that is about 20 times more toxic than the parent compound and the most persistent metabolite stored in adipose tissues.

Chlordane interactions with other agricultural chemicals produced significant biological effects in warm-blooded organisms, indicating a need for additional research on this subject.

Terrestrial Invertebrates

Chlordane has been used extensively to control grubs, ants, snails, and terrestrial invertebrates. Chlordane applied to wheat crops in India at 0.6 kg/ha and higher controlled infestation by two species of termites *(Odontotermes obesus, Microtermes obesi)* and increased grain yield; chlordane applications of 0.4 kg/ha and lower were ineffective (Khan and Singh 1985). Chlordane has been used to control the imported fire ant *(Solenopsis invicta),* although registration for this purpose by EPA has now been withdrawn (Williams and Lofgren 1983). Application of 4.5 g of chlordane per ant mound, applied as an emulsifiable concentrate, resulted in 83 to 94% control 4 to 5 weeks after treatment (Williams and Lofgren 1983). Cricket (*Acheta pennsylvanicus*) nymphs died within one minute of contact with technical chlordane; dead crickets showed cellular disruption of the caecal lining, the malpighian tubules, and the digestive tract (Greenhalgh 1986).

Chlordane, at 1. 12 to 2.24 kg/ha, was lethal to fly and beetle larvae and also caused reductions in populations of various species of soil invertebrates (WHO 1984). Among nontarget soil species, earthworms were especially sensitive. Significant reductions in earthworm populations were recorded following application of 2.2 kg/ha; metabolism was adversely affected in 2 weeks at 13 kg/ha and remained depressed for at least 5 years; at 80 kg/ha, 46% died in 4 days (NRCC 1975). In soil, chlordane effects decreased with increasing soil temperature and organic content; the heptachlor component in technical chlordane had the greatest biological activity to soil fauna (NRCC 1975).

Aquatic Organisms

Signs of chlordane poisoning in fish included hyperexcitability, increased respiration rate, erratic swimming, loss of equilibrium and convulsions; death frequently occurred within 12 h of exposure (NRCC 1975). Chlordane adversely affected sensitive species of fish and aquatic invertebrates at nominal water concentrations between 0.2 and 3.0 µg/L (Table 3). Specifically, reduced survival was measured in shrimp and crabs at water concentrations of 0.2 to 2.0 µg/L, and in freshwater and marine fishes between 1.7 and 3.0 µg/L; immobilization, impaired reproduction, and histopathology were recorded in shrimp, fish, and planarians between 0.8 and 3.0 µg/L; and high accumulations were evident in fish, shrimp, and oysters between 0.2 and 4.2 µg/L. Growth stimulation and high residues were measured in resistant species of algae, such as *Scenedesmus quadricauda,* at media concentrations up to 100 µg chlordane per liter; in sensitive algal species, however, growth was inhibited at water concentrations as low as 10 µg/L (Table 3).

Large intraspecfic and interspecific differences in sensitivity to chlordane were evident (Table 3). Some of this variability was attributed to variations in water temperature, salinity, and sediment loadings; some to the age, condition, and nutritional history of the test organism; and some to the chlordane formulation and isomer tested (NRCC 1975; EPA 1980; and Finley 1980; McLeese and Metcalf 1980; Mayer and Ellersieck 1986). In general, granular chlordane formulations were most toxic, organisms at a young developmental stage and organisms with reduced lipid content were most sensitive, and adverse effects were most pronounced under conditions of elevated water temperatures, reduced salinities, decreased sediment loadings, and increased duration of exposure. Reduced bioavailability and lessened toxicity of chlordane to daphnids was associated with increasing concentrations (up to 200 mg/L) of suspended solids and their associated carbon content (Hall et al. 1986). Sediment loadings of 5.8 mg chlordane per kilogram were fatal to 50% of sandworms (McLeese et al. 1982). Resistance or adaptation to chlordane has been reported in mosquitofish *(Gambusia affinis)* collected from ditches near treated cotton fields; these fish were up to 20 times more resistant than newly exposed fish (NRCC 1975).

Residues of *cis*-chlordane were preferentially stored and magnified over *trans*-chlordane by freshwater fish and invertebrates in ponds treated with technical chlordane at concentrations up to 1.14 µg/L; the *cis* isomer, with an estimated Tb 1/2 of 46 days, persisted longer than did the *trans*- isomer (Johnson and Finley 1980). Tissue concentrations of 106,000 µg total chlordenes per kilogram, on a lipid weight basis, were associated with reduced survival of estuarine invertebrates (Zitko 1978). Moribund amphipods *(Hyallela azteca),* for example, contained 137,000 to 2,180,000 µg/kg lipid of various chlordanes, heptachlors, and chlordenes (Zitko 1978). In fish, chlordane concentrations of 300,000 to 4,000,000 µg/kg lipid weight in tissues were lethal (Zitko 1978).

Cis-chlordane was 8 times more toxic to bluegill *(Lepomis macrochirus)* than was *trans*-chlordane (Johnson and Finley 1980). *Cis*-chlordane was also more toxic to goldfish *(Carassius auratus)* than was *trans*-chlordane because of its comparatively rapid uptake from the medium and lengthy storage in body tissues, estimated at 99 % after 25 days (Feroz and Khan 1979b). The elimination rate of *cis*-chlordane from a cichlid (*Cichlasoma* sp.) was estimated at 2.9% weekly over a 20-week period, with a Tb 1/2 of about 17 weeks; metabolites accounted for 12.5% (dichlorochlordene, oxychlordane, chlordene chlorohydrin, dihydroxyheptachlor, dihydroxydihydrochlordene, plus four unidentified compounds) and unchanged *cis*-chlordane for 87.5 % (Feroz and Khan 1979a).

Table 3. Chlordane effects on selected aquatic organisms. Compound tested was technical chlordane, unless indicated otherwise.

Organism and concentration in medium in ug/L	Effect	Reference[b]
Algae		
Blue-green alga, *Chlamydomonas* sp.		
0.1–50	Stimulatory to growth	1
>100	Inhibitory to growth	1
Estuarine phytoplankton, mixed species		
5	No effect on growth in 5 days	2
10	Daily additions of 10 µg/L for 8 days reduced algal growth rate and carbon uptake. Inhibition persisted for 2–48 h and did not affect community composition	2
Marine dinoflagellate, *Exuviella baltica*		
50	Exposure for 7 days resulted in disintegration of many cells, reduced cell density and reduced carbon fixation. Particle size distribution altered, and this could affect availability of food for particle feeding herbivores	3
Green alga, *Scenedesmus quadricauda*		
0.1–100	Stimulatory to respiration and growth; bioconcentration factor (BCF) ranged from x6,000 to x15,000 in 24 h for all doses, and from x6,700 to x103,000 in 5 days	1, 4
>1,000	Growth inhibition	4
Invertebrates		
Blue crab, *Callinectes sapidus*		
260	50% immobilization in 48 h	5
Dungeness crab, *Cancer magister*		
0.015	No effect on survival or molting	6
0.15	LC50 (37 days), molting inhibited	6
1.3	LC50 (96 h), zoeae	6
220	LC50 (96 h), adults	6
Sand shrimp, *Crangon septemspinosa*		

2	LC50 (96 h)	7
American oyster, *Crassostrea virginica*		
4.2	8% reduction in shell growth in 96 h, BCF of x2,619 in soft parts	8
6.2–10	50% reduction in shell growth in 96 h, BCFof x3,200–x8,300	5, 6, 8
100	BCF of x7,300 after exposure for 10 days	9
Daphnid, *Daphnia magna*		
12.1 and 21.6	Maximum acceptable toxicant concentration (MATC)[a]	6
28	50% immobilization in 96 h	10
97	LC50 (48 h) for chlorinated chlordane	11
152	LC50 (48 h) for chlorinated emulsifiable concentrate	11
270	LC50 (48 h)	12
813	LC50 (48 h) for dechlorinated chlordane	11
1,174	LC50 (48 h) for dechlorinated emulsifiable concentrate	11
Daphnid, *Daphnia pulex*		
2.3	50% immobilization in 48 h for *trans*-nonachlor	13
24	LC50 (48 h)	14, 15
57	LC50 (96 h) for *cis*-chlordane	16
269	LC50 (96 h) for *trans*-chlordane	16
550	LC50 (96 h) for *cis*-photochlordane	16
930	LC50 (96 h) for oxychlordane	16
Planarian, *Dugesia dorotocephala*		
0.2	No deaths in 5 days	17
>1.0	Impaired reproduction after 10-day exposure	17
~3.0	LC50 (5 days)	17
10.0	LC100 (10 days)	17
Amphipod, *Gammarus fasciatus*		
40	LC50 (96 h), 95% confidence interval of 21–60 µg/L	14, 15
Amphipod, *Hyallela azteca*		
97	50% immobilization in 168 h	10
Freshwater bivalve mollusk, *Lamellidens marginalis*, exposed to 0.12 mg technical chlordane/L for up to 30 days		
2 days	Residues, in mg/kg FW, were 5.0 in gill, 3.6 in foot, 3.1 in muscle, and 2.2 in intestine	26
8 days	Residues, in mg/kg FW, ranged between 2.4 in gill and 1.1 in muscle	26

30 days	Residues, in mg/kg FW, were 1.0 in gill, 1.0 in foot, 0.4 in intestine, and 0.1 in muscle	26
Sandworm, *Nereis virens*		
220	LC50 (12 days), but no deaths in 96 h. At 96 h, signs of stress included everted proboscis, loss of equilibrium, emergence from sediments, and failure to burrow	18
Crayfish, *Orconectes nais*		
31.6	LC50 (35 days)	14
50	LC50 (96 h)	14
Korean shrimp, *Palaemon macrodactylus*		
11	LC50 (96 h)	15
Grass shrimp, *Palaemonetes pugio*		
4.2	LC15 (19 h), BCF about x1,070	8
4.8	LC50 (96 h), BCF of x1,900–x2,300	8
Brown shrimp, *Penaeus aztecus*		
2.4	50% immobilization in 48 h	5
Pink shrimp, *Penaeus duorarum*		
0.24	LC10 (96 h), whole body BCF of x2,960 in survivors	8
0.4	BCF of x4,000–x6,000 in 96 h	8
4.4	LC50 (48 h)	8
Stonefly, *Pteronarcy californica*		
15	LC50 (96 h), 95% confidence interval of 9–24 µg/L	14, 15
Daphnid, *Simocephalus serrulatus*		
20	LC50 (48 h)	14, 15
Fish		
Goldfish, *Carassius auratus*		
13	LC50 (96 h) for *cis*-photochlordane	16
15	LC50 (96 h) for oxychlordane	16
26	Exposed for 24 h to *cis*-chlordane. Whole body BCF at 10 and 25 days after exposure were x2,280 and x1,820, respectively	19
27	LC50 (96 h) for *cis*-chlordane	16
82	LC50 (96 h)	6
440	LC50 (96 h) for *trans*-chlordane	16
Sheepshead minnow, *Cyprinodon variegatus*		
0.5 and 0.8	MATC[a]	20
0.8	Reduced hatch during continuous exposure	20
1.7	Some deaths in second-generation fish during	20

	continuous exposure	
2.8	Some deaths in adult fish during exposure for 189 days	20
3.3	No deaths in 28 days, whole body BCF of x3,333	8
7.1	Equilibrium loss in fry after exposure for 10 days	8
12.5–24.5	LC50 (96 h)	8, 20
15	LC25 (96 h), BCF up to x18,700 in survivors	8
36	No effect on fertilization success or embryo survival after adults exposed for 28 days	8
Common carp, *Cyprinus carpio*		
3.0	LC50 (96 h)	6
Threespine stickleback, *Gasterosteus aculeatus*		
90–160	LC50 (96 h)	6, 15
Freshwater catfish, *Heteropneustes fossilis*		
150	No deaths in 96 h	21
247	Muscle glycogenolysis and hyperglycemia in 2–12 h	21
275	LC50 (96 h)	21
3,500	LC100 (96 h)	21
Channel catfish, *Ictalurus punctatus*		
7–46	LC50 (96 h)	14
Pinfish, *Lagodon rhomboides*		
5.4	LC30 (94 h), whole body BCF of x3,070	8
6.4	LC50 (96 h), BCF up to x7,500	8
Bluegill, *Lepomis macrochirus*		
1.2 and 2.2	MATC[a]	10
7.1–17	LC50 (96 h) for *cis*-chlordane	14, 16
9.2	LC50 (96 h) for oxychlordane	16
12	LC50 (48 and 96 h) for *cis*-photochlordane	16, 22
19–85	LC50 (96 h)	6, 10, 14, 15
41	LC50 (96 h) for chlorinated technical chlordane	11
50.5–140	LC50 (96 h) for *trans*-chlordane	14, 16
62	LC50 (96 h) for chlorinated emulsifiable concentrate	11
582	LC50 (96 h) for dechlorinated technical chlordane	11
800	LC50 (96 h) for dechlorinated emulsifiable concentrate	11

Largemouth bass, *Micropterus salmoides*		
3.0	LC50 (96 h)	14
Striped bass, *Morone saxatilis*		
11.8	LC50 (96 h)	6
Striped mullet, *Mugil cephalus*		
3.2	LC50 (48 h)	5
Cutthroat trout, *Oncorhynchus clarki*		
27	LC50 (96 h)	14
Coho salmon, *Oncorhynchus kisutch*		
14–56	LC50 (96 h)	6, 14, 15
Rainbow trout, *Oncorhynchus mykiss*		
8–47	LC50 (96 h)	6, 14, 15, 24
Chinook salmon, *Oncorhynchus tshawytscha*		
57	LC50 (96 h)	15
Sea lamprey, *Petromyzon marinus*		
1,000	LC100 (14 h)	9
Fathead minnow, *Pimephales promelas*		
25–115	LC50 (96 h)	10, 14, 15
Indian carp, *Saccobranchus fossilis*		
420	LC50 (96 h)	23
Brown trout, *Salmo trutta*		
11	LC50 (96 h)	14
Brook trout, *Salvelinus fontinalis*		
0.32	Adverse effects during chronic exposure	10
22	No deaths in 96 h	25
30-47	LC50 (96 h)	6, 10, 25

[a] MATC = maximum acceptable toxicant concentration. Lower value in each MATC pair indicates highest concentration tested producing no measurable effect on growth, survival, reproduction, and metabolism during chronic exposure; higher value indicates lowest concentration tested producing a measurable effect.

[b] 1. Glooschenko et al. 1979; 2. Biggs et al. 1978; 3. Magnani et al. 1978; 4. Glooschenko and Lott 1977; 5. Mayer 1987; 6. EPA 1980; 7. McLeese and Metcalfe 1980; 8. Parrish et al. 1976; 9. NRCC 1975; 10. Cardwell et al. 1977; 11. Randall et al. 1979; 12. Hall et al. 1986; 13. Passino and Smith 1987; 14. Johnson and Finley 1980; 15. EPA 1973; 16. Podowski et al. 1979; 17. Best et al.; 1981; 18. McLeese et al. 1982; 19. Feroz and Khan 1979b; 20. Parrish et al. 1978; 21. Mirsha and Srivastava 1984; 22. Sudershan and Khan 1980; 23. Verma et al. 1982; 24. Mayer and Ellersieck 1986; 25. Zitko 1979; 26. Agrawal 1986.

Photoisomers seem to be more toxic than the parent form. For example, *cis*-photochlordane was about twice as lethal to bluegills and goldfish than was *cis*-chlordane (Sudershan and Khan 1980). Bluegills exposed to 5 µg/L of radiolabeled *cis*-photochlordane or *cis*-chlordane for 48 h accumulated *cis*-chlordane from the medium by a factor of x78, and *cis*-photochlordane by a factor of x 140 (Sudershan and Khan 1980). During the next 6 weeks, 20% of the cis-chlordane was eliminated in a linear pattern, and about 50% was eliminated in 46 days. Elimination of *cis*-photochlordane followed a biphasic pattern and was most rapid during the first 3 weeks; 40% was eliminated in the fast 6 weeks, and 50% was eliminated in 15 weeks. Less than 7% of the radioactivity retained in *cis*-chlordane-treated bluegills was in the form of two conjugates, compared with 16% in the form of 14 metabolites for *cis*-photochlordane. No oxychlordane was found in bluegill tissues after treatment; this compound is one of the predominant metabolites found in chlordane-treated rodents and cockroaches. Thus, absence of epoxidation and presence of a mechanism of hydroxylation followed by conjugation seems to be the most active mode of chlordane metabolism in bluegill (Sudershan and Khan 1980).

Cis-photochlordane was about one-tenth as toxic to *Daphnia pulex* than was *cis*-chlordane (Podowski et al. 1979). This is in sharp contrast to the pattern shown in bluegill and goldfish (Sudershan and Khan 1980); further, *cis*-photochlordane and *cis*-chlordane toxicity to mice and houseflies was about the same (Podowski et al. 1979), which demonstrates the difficulty in generalizing about the comparative toxicity of chlordane isomers.

Amphibians and Reptiles

Shortly after chlordane was applied to wooden huts in Australia for termite control, large numbers of dead skinks *(Morethia boulengeri, Lerista puctorittata)* and frogs *(Litoria caerulea, L. peronii)* were discovered, presumably killed by the chlordane (Henle 1988). Toad *(Bufo arenarum)* embryos survived 0.5 mg technical chlordane per liter for 8 days but died by day 20; all embryos held in 15 mg/L were dead by day 15 (Juarez and Guzman 1984). For tadpoles of the common toad *(Bufo bufo)* a 48-h LC50 of 2 mg/L was reported (WHO 1984).

Birds

Signs of chlordane intoxication in birds include sluggishness, drooped eyelids, fluffed feathers, low crouching on perch, reduced food intake, and weight loss. Later, afflicted animals rested on their breasts, wings spread, quivering and panting rapidly, back arched, neck arched over the back, and convulsing (Stickel et al. 1983). Signs of intoxication appeared within 5 min, and death usually occurred in the first 8 days of exposure; remission took up to 4 weeks in some birds (Hudson et al. 1984).

The most sensitive birds tested against technical chlordane were California quail *(Callipepla californica),* with an acute oral LD50 of 14.1 mg/kg BW; ring-necked pheasant (*Phasianus colchicus*), with an acute oral LD50 of 24 to 72 mg/kg BW; and European starlings (*Sturnus vulgaris*) fed diets containing 1.5 mg/kg ration for 57 days or 6.25 mg/kg for 24 days (Table 4). Accumulations of various chlordane isomers and metabolites were evident in chickens (*Gallus* sp.) fed diets containing as little as 0.1 mg technical chlordane per kilogram of feed for 6 weeks or 0.3 mg/kg for 4 weeks (NRCC 1975). Vapor toxicity of chlordane is persistant. In one instance, a room used for housing rock doves was sprayed with a chlordane solution; walls and floors were then scrubbed and the room left unoccupied for 2 months. When rock doves were returned to the room, enough chlordane remained to be lethal to all birds (Ingle 1965). Similar cases are reported for mice, presumably after use of very concentrated chlordane solutions (Ingle 1965).

Table 4. Chlordane effects on selected birds.

Organism and other variables	Effect	Reference
Red-winged blackbird, *Agelaius phoeniceus*, fed diets containing		
10 mg/kg for 84 days	Residue of 1.8 mg *cis*-chlordane per kilogram body weight (BW), fresh weight (FW)	Stickel et al. 1983
50 mg/kg for 42 days	Whole body *cis*-chlordane content of 9.2 mg/kg FW	Stickel et al. 1983
100 mg/kg for 21 days	Whole body *cis*-chlordane content of 14.8 mg/kg FW	Stickel et al. 1983
Plus 3 or 7 days off dosage	Whole body *cis*-chlordane content of 5.4 and 2.6 mg/kg FW, respectively	Stickel et al. 1983
200 mg/kg diet	LD50 within 9 days	Stickel et al. 1983
Mallard, *Anas platyrhynchos*		
Single oral dose, age 4–5 months, 1,200 mg/kg BW	LD50	Hudson et al. 1984

858 mg/kg diet for 5 days followed by 3 days of clean diet, ducklings age 10 days	LD50	Hill et al. 1975
709 mg/kg diet	LD50	NRCC 1975
Birds, 4 species, from marsh treated with 1.12 kg chlordane per hectare	No reproduction in blue-winged teal (*Anas discors*) and northern shovelers (*Anas clypeata*); reproduction inhibited by 60% in coots (*Fulica americana*) and red-winged blackbirds (*Agelaius phoeniceus*); disruption of food cycles in marsh was probable cause	NRCC 1975
Birds, 4 species, fed diets containing 71% cis-chlordane and 23% *trans*-chlordane at 50–500 mg/kg diet	Oxychlordane concentrations in brain of dead birds ranged from 9.4–22.1 mg/kg FW in brown-headed cowbirds (*Molothrus ater*), common grackles (*Quiscalus quiscula*), and red-winged blackbirds. In European starlings (*Sturnus vulgaris*), oxychlordane ranged from 5.0 to 19.1 mg/kg FW in birds that died, and from 1.4 to 10.5 mg/kg FW in sacrificed birds	Stickel et al. 1983
Birds, 3 species, fed diets containing 150 mg technical chlordane per kilogram	LD50 reached in 6–7 days for starlings, cowbirds, and red-winged blackbirds	Stickel et al. 1979
California quail, *Callipepla californica*		
Single oral dose of 14.1 mg/kg BW	LD50	Hudson et al. 1984
Northern bobwhite, *Colinus virginianus*		
10–120 mg/kg diet for 14 weeks	LD50	NRCC 1975; WHO 1984
250 mg/kg diet for 10 days, juveniles	LD50	WHO 1984
250 mg/kg diet for 100 days, adults	LD50	WHO 1984
Japanese quail, *Coturnix japonica*		
25 mg/kg diet, 4 weeks	No effect on survival, weight gain, or activity	NRCC 1975
200 mg/kg diet, 7 days	LD100	NRCC 1975
14-day-old chicks fed treated diets for 5 days, then untreated diets for 3 days		
203 mg/kg diet	No effect on survival or food consumption	Hill and Camardese 1986
308 mg/kg diet	LD50	Hill and Camardese 1986
370 mg/kg diet	LD73, reduced food consumption	Hill and Camardese 1986
500 mg/kg diet	LD93, reduced food consumption	Hill and Camardese 1986
Chicken, *Gallus* sp.		
Fed diet containing 0.1 mg/kg for 6 weeks	Egg chlordane residue about 0.2 mg/kg FW, and fat residue about 0.33 mg/kg FW	NRCC 1975
Adults fed diet containing 0.3 mg/kg for 4 weeks	No adverse effects on growth, egg hatchability, or chick growth	NRCC 1975
Fed diet containing 10 mg/kg for 5 days	Egg chlordane residue about 4 mg/kg FW	NRCC 1975
220–230 mg/kg BW	Acute oral LD50	NRCC 1975
Ring-necked pheasant, *Phasianus colchicus*		
Single oral dose of 24–72 mg/kg BW	LD50	Hudson et al. 1984
50 mg/kg diet for 100 days, juveniles	LD50	WHO 1984
318 mg/kg diet	LD50	NRCC 1975
430 mg/kg diet for 5 days, then clean diet	LD50	Hill et al. 1975

for 3 days, juveniles		
European starling, *Sturnus vulgaris*		
Fed diet containing 1.5, 6.25, 25 or 100 mg chlordane per kilogram	Time for 50% mortality was 57 days for 1.5 mg/kg diet, 24 days for 6.25 mg/kg diet, 6.5 days for the 25 mg/kg diet, and 3.25 days for the 100 mg/kg diet	Stickel et al. 1979
Fed diet containing 100 mg nonachlor per kilogram for 35 days	8% dead	Stickel et al. 1983
200 mg chlordane per kilogram diet	LD50 usually within 14 days	Stickel et al. 1983
500 mg chlordane per kilogram diet	LD50 in 5 days	Stickel et al. 1983
Common barn owl, *Tyto alba*, adults		
Fed diets containing 75 mg/kg until 50% died; survivors sacrificed and residues measured	Mortality reached 50% on day 40. Maximum residues in brains of birds dying during exposure (or sacrificed), in mg/kg FW, were 6.5 (9.0) for *cis*-chlordane, 4.5 (9.0) for trans-nonachlor, 3.2 (9.0) for trans-chlordane, and 1.0 (2.0) for cis-nonachlor	O. H. Pattee, Patuxent Wildlife Research Center, personal communication
Fed diets containing 150 mg/kg until 50% died; survivors sacrificed and residues measured	Mortality reached 50% on day 17. Maximum residues in brains of owls dying during exposure (or sacrificed), in mg/kg FW, were 5.1 (1.8) for *cis*-chlordane, 3.6 (1.8) for *trans*-chlordane, 3.2 (2.1) for *trans*-nonachlor, and 0.9 (0.4) for *cis*-nonachlor	O. H. Pattee, Patuxent Wildlife Research Center, personal communication

Reproductive impairment was reported in several species of waterfowl from a marsh treated with 1.12 kg technical chlordane per hectare (Table 4). Recent studies by Lundholm (1988) with two species of ducks *(Anas* spp.) and the domestic chicken (*Gallus* sp.) demonstrated that various organochlorine compounds, including chlordane, interfered (in a dose-dependent manner) with reproduction by reducing the binding of progesterone to its cytoplasmic receptor in the shell gland mucosa of birds, especially ducks.

The lethal effect of technical chlordane in birds is attributed primarily to chlordane metabolites, especially oxychlordane, and to a lesser extent heptachlor epoxide (Stickel et al. 1983). Oxychlordane was the most persistent chlordane component in avian brain tissues. The half-time persistence of oxychlordane in brain was 63 days, and 95% loss was estimated in 280 days; the Tb 1/2 for heptachlor epoxide was 29 days, and for *trans*-nonachlor it was 19 days (Stickel et al. 1979). Oxychlordane residues in brain tissue approaching 5 mg/kg FW were considered within the lethal hazard zone to birds (Stickel et al. 1979).

Technical heptachlor contains about 15 % *cis*-chlordane and 2.5% *trans*-chlordane. Diets containing 50 mg technical heptachlor per kilogram fed to brown-headed cowbirds *(Molothrus ater),* red-winged blackbirds *(Agelaius phoeniceus),* common grackles *(Quiscalus quiscula),* and European starlings produced 50% mortality in 9 to 24 days; birds that died contained 9.2 to 27 mg oxychlordane per kilogram of FW brain and survivors contained 2.7 to 7.8 mg/kg (Stickel et al. 1979). Red-winged blackbirds were fed diets containing 10 mg technical chlordane per kilogram for 84 days, 50 mg/kg for 42 days, or 100 mg/kg for 21 days; all contained about 17% of the total diet fed as *cis*-chlordane, with whole body residues in mg/kg FW of 1.8, 9.2, and 14.8; accumulations of *trans*-chlordane were negligible (Sticker et al. 1983).

Chlordane interactions with other agricultural chemicals are significant and merit additional research. In one study, male Japanese quail *(Coturnix japonica)* pretreated for 8 weeks with 10 mg chlordane per kilogram of diet had increased resistance to parathion, but not to paraoxon, as judged by cholinesterase activity (Ludke 1977). In another study, northern bobwhites *(Colinus virginianus)* treated with 10 mg chlordane per kilogram of diet for 10 weeks, followed by endrin stress, had greater accumulations of chlordane in the brain than did birds treated only with chlordane (Ludke 1976).

Mammals

Concern for the continued widespread use of chlordane is centered around its carcinogenicity in mice, *Mus* sp. (Ewing et al. 1985). Chlordane produced liver cancer in both sexes of two different strains of domestic mice (EPA 1980; WHO 1984; Tojo et al. 1986; Table 5). A dose-dependent incidence of hepatocellular carcinoma was evident in mice fed chlordane in their diets; frequency of liver carcinomas was not significantly different from controls at dietary levels of 5 mg/kg and lower but were greatly elevated (i.e., 70% frequency) at dietary levels of 50 mg/kg and higher (EPA 1980). In contrast to mice, chlordane was not a hepatic carcinogen in rats at dietary levels up to 64 mg/kg ration (WHO 1984; EPA 1988); however, a dose-related increase in follicular cell thyroid neoplasms and malignant fibrous histocytomas was recorded in chlordane-exposed rats Ohno et al. 1986). In humans, no increased evidence of cancer was proven among employees in chlordane manufacturing facilities, although there was a statistically significant increase in death rate from cerebrovascular disease in that group (Klaassen et al. 1986).

Human toxicity data for chlordane usually are obtained after accidental exposure through spillage onto clothing or ingestion (Ingle 1965; NRCC 1975; EPA 1980). In one case, a 15-month-old girl accidentally swallowed a mouthful of chlordane suspension and within 3 h displayed tremors and incoordination. Repeated seizures developed and she was treated with ethyl chloride, amobarbitol, and gastric lavage with magnesium sulfate; ataxia and excitability disappeared in about 3 weeks. At age 26, she was in excellent health and seemed not to have experienced latent effects from the childhood incident (WHO 1984). Other cases of accidental chlordane poisoning in children are documented, and all seem to have recovered completely after treatment (WHO 1984).

Symptoms of acute chlordane poisoning in humans include irritability, salivation, labored respiration, muscle tremors, brain wave abnormalities, incoordination, convulsions, deep depression, and sometimes death (IARC 1979; EPA 1980, 1988). Signs of acute chlordane intoxication in other mammal species are similar to those in humans and may also include aplastic anemia and acute leukemia; cyanosis; pathology of gastrointestinal tract, liver, kidney, lung, and heart; pulmonary congestion; degenerative changes in the central nervous system; impaired uptake and utilization of glucose; interference with immunocompetence response; diarrhea; avoidance of food and water; enhanced estrone metabolism; increased production of hepatic mixed function oxidase enzymes; altered enzyme activity in brain and in kidney cortex; enlarged liver; hair loss; abdominal distention; hunched appearance; inhibited oxidative phosphorylation in liver mitochondria; and thyroid carcinoma (Saxena and Karel 1976; IARC 1979; Reuber and Ward 1979; WHO 1984; Barnett et al. 1985; Johnson et al. 1986, 1987; Klaassen et al. 1986; EPA 1988; Suzaki et al. 1988). Acute oral LD50 values for technical chlordane and sensitive mammals usually ranged between 25 and 50 mg/kg BW (Table 5). Chlordane-related compounds (i.e., *cis*-chlordane, *trans*-chlordane, heptachlor, heptachlor epoxide) stimulate superoxide (O_2^-) generation in guinea pig leucocytes, alter membrane potential, and increase intracellular calcium concentration; toxicity of individual compounds seems to be related to superoxide generation (Suzaki et al. 1988). Metabolism of chlordane isomers results in oxychlordane, a metabolite that is about 20 times more toxic to rats than is the parent compound and is the most persistent metabolite stored in rat adipose tissue (Menzie 1978; EPA 1980). Oxychlordane accounted for 53% in females and 63% in males of all chlordane isomers in fat of rats killed 24 h after a single oral dose of 1.0 mg/kg BW technical chlordane (Nomeir and Hajjar 1987). Acute oral LD50 values in the rat, in mg/kg BW, were 19.1 for oxychlordane; 89 to 392 for *cis*-chlordane; 200 to 590 for technical chlordane; 327 for *trans*-chlordane; >4,600 for chlordane, 3-chlordene, 1-hydroxychlordene, chlordene epoxide, 1-hydroxy, and 2,3-epoxy chlordane; and >10,000 for 2-chlorochlordene (Table 5).

Chlordane adversely affects growth and fertility of laboratory animals (Talamantes and Jang 1977; IARC 1979; Klaassen et al. 1986; EPA 1988; Table 5). Neonatal exposure of mice to chlordane retards growth, as judged by lowered body weights during the first 12 weeks (Talamantes and Jang 1977). No fetotoxic or teratogenic effects were observed in rats born to dams fed chlordane in their diets for 2 years at levels up to 300 mg/kg diet; however, pups nursed by dams consuming chlordane at 150 or 300 mg/kg diet developed signs of toxicity (EPA 1988). In uterine mucosa of the rabbit, chlordane isomers (as well as isomers of DDE and polychlorinated biphenyls) reduced the binding of progesterone to its cytoplasmic receptor in a dose-dependent manner, which suggests a pathway to account for chlordane-induced reproductive impairment (Lundholm 1988).

Table 5. Chlordane effects on selected mammals.

Organism, dose, and other variables	Effects	Reference
Cow, *Bos bovis*		
Oral doses equivalent to 1, 10, or 100 mg/kg diet for 60 days, then no dose for 30 days	At 1 mg/kg diet equivalent, total chlordane in fat increased from 0.24 mg/kg at day 30 to 0.47 at day 60; 30 days later, residues remained elevated at 0.45 mg/kg. The same pattern was seen at higher dose levels but residues were higher at 1.2–1.5 mg/kg in the 10 mg/kg diet group, and 2.6–4.0 in the 100 mg/kg group	Nomeir and Hajjar 1987
Fed diets containing 10 mg/kg for 10 days	Milk contained less than 50 µg/L	NRCC 1975
Fed diets containing 20 mg/kg for 150 days	Milk contained less than 200 µg/L	NRCC 1975
25–90 mg/kg body weight (BW)	Acute oral LD50	WHO 1984
Dog, *Canis familiaris*		
Fed diets containing 0.3, 3, 15, or 30 mg chlordane per kilogram of food for 2 years	Liver abnormalities in 15 and 30 mg/kg groups; no adverse effects at lower doses on behavior, appearance, survival, weight gain, or blood chemistry. In the 3 mg/kg group, equivalent to 0.075 mg/kg BW daily, maximum residue in fat was 3.6 mg/kg	NRCC 1975; WHO 1984; EPA 1988
Daily oral dose ranging between 5 and 200 mg/kg BW	Dose-dependent mortality. All died between 25 days and 93 weeks	WHO 1984
Single oral dose of 200–700 mg/kg BW	No deaths	WHO 1984
Goat, *Capra* sp.		
180 mg/kg BW	Acute oral LD50	WHO 1984
Guinea pig, *Cavia* spp.		
Males exposed daily for 90 days to 67 mg/kg BW through dermal painting	Mild degenerative changes in skin and testes	WHO 1984
Hamster, *Cricetus* spp.		
1,720 mg/kg BW	Acute oral LD50	EPA 1980; WHO 1984
Human, *Homo sapiens*		
100 µg/L	Reduced growth and altered cell morphology in human cell cultures	EPA 1980
25–50 mg/kg BW	Acute lethal oral dose	WHO 1984
100 mg/kg BW	Fatal	IARC 1979
Female swallowed 6g of chlordane, equivalent to 104 mg/kg BW	Death in 9 days	WHO 1984
Contamination of water supply in Chattanooga, Tennessee, by up to 1.2 g	Gastrointestinal and neurological symptoms in 13 reported cases	WHO 1984

chlordane per liter		
Cynomolgus monkey, *Macaca* spp.		
Inhalation for 90 days of air containing 10 µg technical chlordane per liter	No measurable effect	Khasawinah et al. 1989
Indian desert gerbil, *Meriones hurrianae*		
Males dosed intramuscularly at 2.5 mg/kg BW every 3 days for 45 days	Hyperproteinemia, hyperglycemia, and enhanced serum alkaline and acid phosphatase activities	WHO 1984
Single intramuscular injection of 25, 50, or 75 mg/kg BW	Dose-dependent hyperglycemia, due to increased production of liver glucose in blood of treated animals, reaching a maximum glucose level about 1 h after injection, persisting for up to 3 days, and approaching control levels within 1 week	Saxena and Karel 1976
Mouse, *Mus* spp.		
On days 2, 3, and 4 of life, each received 0.075 or 0.15 mg of either *cis*-chlordane or *trans*-chlordane	Depressed growth and delayed development in eye and vaginal opening during first 12 weeks; all normal at necropsy after 15 weeks	Talamantes and Jang 1977
Oral doses of 0.08 or 0.25 mg daily for 30 days, equivalent to 100 and 300 mg/kg BW	Significant dose-related reduction in size of seminiferous tubules and in percentage of damaged tubules. High dose group experienced 24–58% reduction in spermatogenesis (and high death rate), low dose group 11–21% reduction, and controls 0.5–6.1% reduction	Balash et al. 1987
0.09 mg/kg BW daily for 2 years, equivalent to 0.76 mg/kg diet	Increased liver to BW ratios in both sexes. At higher dietary concentrations equivalent to 0.43 and 1.1 mg/kg BW daily, liver necrosis was observed in males	EPA 1988
Daily oral doses for 14 days of 0.1, 4, or 8 mg *trans*-chlordane per kilogram BW	Significant dose-related increase in liver weight and leukocytes; no effect on immunocompetence	Johnson et al. 1986
Pregnant females treated with 0.16 or 8 mg/kg BW throughout gestation	Decreased immune competence in offspring of high-dose group challenged with oxazolone at age 101 days	WHO 1984
Single oral dose of *cis*-chlordane of 1.0 mg/kg BW	Peak tissue concentrations reached, in µg/kg FW, were 1,180 in liver, 880 in fat, 349 in kidney, 248 in lungs, 164 in muscle, 92 in testes, and 68 in brain. Peak concentration in blood of 113 µg/L reached in 8 h; 34% of total dose excreted in feces by 12 h after treatment. After 14 days, measurable residues detected in gonad, muscle, fat, and kidney	Ewing et al. 1985
Offspring from parents given 1.0 or 2.5 mg/kg BW for 7 consecutive days	Impaired conditioned avoidance response behavior, and hyperactivity	WHO 1984

Fed diets containing 5, 25, or 50 mg technical chlordane per kilogram ration for 18 months	Dose-related incidence of hepatic nodular hyperplasias in the 25 and 50 mg/kg diets and an increased incidence of hepatomas in the male 5 and 25 mg/kg groups. Controls experienced a high incidence of premature deaths	Epstein 1976
Females injected intraperitoneally with 25 mg/kg BW once weekly for 3 weeks	Fertility reduced by about 50%	EPA 1988
Fed diets containing 25 to 100 mg chlordane per kilogram food for six generations	At 100 mg/kg, decreased viability in first and second generations and no offspring in third generation. At 50 mg/kg, viability was reduced in fourth and fifth generations. No significant effects in the 25 mg/kg group, even after six generations	WHO 1984
Males fed diets containing 29.9 or 56.2 mg technical chlordane per kilogram for 80 weeks	Frequency of liver tumors was 88% in high-dose group, 33% in low-dose group, and 19% in controls	EPA 1980
Females fed diets containing 30 or 64 mg technical chlordane per kilogram for 80 weeks	Frequency of liver tumors was 70% in high-dose group, 6% in low-dose group, and 4% in controls	EPA 1980
Males given single dose of 50 or 100 mg/kg BW, then mated with untreated females	No dominant lethal changes produced	EPA 1980
390–430 mg/kg BW	Acute oral LD50	IARC 1979; EPA 1980
Rabbit, *Oryctolagus* sp.		
Oral doses of 1, 5, or 15 mg/kg BW daily on days 6–18 of gestation	Some miscarriages in 1 and 15 mg/kg groups; no changes in behavior, appearance, or body weight; no teratogenic effects observed	WHO 1984
Dosed orally with 14.3 mg of radiolabeled *trans*-chlordane daily for 10 weeks and killed 2 weeks after the last dose	Residues were highest in abdominal and subcutaneous fat (235 mg/kg FW), followed by heart and spleen (75–91 mg/kg), then liver, brain, and blood (25–44 mg/kg)	Nomeir and Hajjar 1987
20 mg/kg BW, single intravenous injection	LD74	Ingle 1965
Dermal exposure for 90 days, equivalent to 20–40 mg/kg BW	LD50	WHO 1984
Dosed orally with *cis*-chlordane at 67 mg/kg BW, or *trans*-chlordane at 30 mg/kg BW every 4 days for a total of 4 doses, then killed 5 days after the last dose	Residues in the *trans*-chlordane group were higher (17–77 mg/kg) than in the *cis*-chlordane group (8–67 mg/kg) although *trans*-chlordane was administered at a much lower dose. Fat and kidney usually contained the highest concentrations, and brain the lowest. Oxychlordane was measured in all tissues at 0.1 mg/kg in brains, 11 mg/kg in fat, and 0.5 to 2 mg/kg in liver, muscle, and kidney	Nomeir and Hajjar 1987
100–500 mg/kg BW	Acute oral LD50	Ingle 1965; EPA 1980
780–1,200 mg/kg BW	Acute dermal LD50; death preceded by skin	WHO 1984

	irritation, tremors, and convulsions	
Sheep, *Ovis aries*		
Single oral dose of 500 mg/kg BW	Incoordination and partial blindness; full recovery in 5–6 days	WHO 1984
Single oral dose of 1,000 mg/kg BW	Severe respiratory and nervous signs in 16 h, and death in 48 h	WHO 1984
Baboon, *Papio anubis*		
Fed diets containing chlordane, equivalent to 0.1–1.0 mg/kg BW daily, for 2 years	At 1.0 mg/kg BW, cytochrome P-450 activity was significantly increased, but no other significant effects were recorded on general health or on any major organ system	WHO 1984
Rat, *Rattus* spp.		
Inhalation of air for various intervals containing technical chlordane		
0.1 µg/L, 90 days	Adverse biological response	Khasawinah et al. 1989
5.8 or 28.2 µg/L, 28 days	No measurable difference from controls at low dose; impaired liver function at high dose	Khasawinah et al. 1989
154 µg/L, 5 days	Death	Khasawinah et al. 1989
413 µg/L, 2 days	Death	Khasawinah et al. 1989
Fed technical chlordane at dietary levels of 1, 5, or 25 mg/kg, equivalent to daily doses of 0.045, 0.229, and 1.175 mg/kg BW respectively, for 130 weeks (2.5 years)	No significant effects on hematology, clinical chemistry, body weight, or survival rate. Dose-dependent hepatocellular necrosis (34% in high-dose group); liver adenomas in males and hepatocellular swelling in females from the high-dose group	EPA 1988
0.05 mg radiolabeled *trans*-chlordane per kilogram BW, single oral dose, residues measured over 96 h after exposure	Maximum resides, in mg/kg FW, and time after administration were: liver, 0.1, 2 h; adipose tissue, 0.09, 96 h; kidney, 0.07, 4 h; skin, 0.03, 8 h; brain, 0.01, 4 h; muscle, 0.008 4 h; and blood 0.003, 4 h. Half-time persistence was 6.5–13 h for the rapidly decreasing phase and 4.8–8.9 days for the slowly decreasing phase	Ohno et al. 1986
Daily intraperitoneal injections of technical chlordane at 0.15, 1.75, or 25 mg/kg daily for 42 days	Dose-dependent alterations of brain potentials without behavioral signs of chronic toxicity	EPA 1980
Single oral dose of 0.2 mg/kg BW of *cis*-chlordane, *trans*-chlordane, or oxychlordane	Maximum residues in fat after 24 h, in mg/kg FW, were 0.3 for *cis*-chlordane, 0.7 for *trans*-chlordane, and 0.5 for oxychlordane	Nomeir and Hajjar 1987
Single oral dose of 0.2 or 1.0 mg/kg BW technical chlordane	Maximum residues in fat at 24 h, in mg/kg FW, were 0.5 for the low-dose group, and 3.7 for the high-dose group	Nomeir and Hajjar 1987
Fed diets containing 0.3, 3, 15, 30, or 60 mg technical chlordane per kilogram diet for 3 generations	Levels up to and including 30 mg/kg diet had no measurable effect on fertility, number of young produced, growth, or mortality rate; no gross or microscopic differences between the	NRCC 1975; WHO 1984

	groups. At 60 mg/kg, the second F_3 generation litters had elevated mortality (11%) during the latter part of the nursing period; these animals also showed gross and microscopic pathology	
Single oral dose of 1.0 mg *cis*-chlordane per kilogram BW	Peak tissue concentration, in mg/kg FW, were noted within 4 h after treatment: liver, 1.9; fat, 1.2; kidney, 0.7; lung, 0.3; brain 0.2; testes, 0.1; muscle, 0.1; and blood, 0.08. After 12 h, 7% was excreted, and after 3 days, 83% was voided	Ewing et al. 1985
Single oral dose of 1.0 mg/kg BW	About 50% excreted in feces after 1 day and 90% in 7 days; only 2–3% of the dose was detected in the urine	Nomeir and Hajjar 1987
Fed oxychlordane in diets for 90 days at rate equivalent to 2.0 mg/kg BW daily	No gross pathology or histological lesions	NRCC 1975; WHO 1984
Fed 2.5, 25, or 75 mg technical chlordane per kilogram of diet for 2 years	Severe toxic signs at 25 and 75 mg/kg; liver damage at 2.5 mg/kg diet	WHO 1984
Long-term feeding studies at dietary concentrations between 5 and 320 mg technical chlordane per kilogram	Reduced survival and growth at dietary levels >150 mg/kg; liver enlargement and micropathology at >20 mg/kg; no effect on reproduction at 150 mg/kg diet; no adverse effects at 5 mg/kg diet	Ingle 1965
Fed *cis*-chlordane at dietary levels of 0.5, 15, 25, or 35 mg/kg	Increased mortality and growth retardation in 4–5 months at 35 mg/kg diet; growth normal in other groups; some liver damage in 25 and 35 mg/kg groups	WHO 1984
Daily oral dose of 6.5–25 mg technical chlordane per kilogram BW, for 15 days	No tremors or convulsions; however, dose-related liver pathology was noted	WHO 1984
Single oral dose of 10 mg radiolabeled *trans*-chlordane per kilogram BW	Maximum residues, in mg/kg FW and time after administration were: liver, 21, 4 h; kidney, 18, 4h; adipose tissue, 11, 16 h; skin, 5, 8 h; brain, 3.4, 4 h; muscle 1.4, 4 h; and blood, 0.6, 4 h; half-life of 5–12 h for the fast component, and 4.3–7.3 days for the slow component	Ohno et al. 1986
Fed diets containing 15 or 25 mg/kg of *cis*-chlordane for 78 weeks	No adverse effects on liver at 15 mg/kg diet; some effects at 25 mg/kg	NRCC 1975
Fed *trans*-chlordane at dietary levels of 15, 25, 35, or 75 mg/kg diet	Decreased survival, liver damage, and growth retardation of males in 8 months at 75 mg/kg diet; growth normal at other doses	WHO 1984
19.1 mg oxychlordane per kilogram BW	Acute oral LD50	WHO 1984
20 mg technical chlordane per kilogram diet for 350 days	Residues in mg/kg FW, were about 20 for adipose tissue, 0.8 for liver, and 0.2 for heart	NRCC 1975
Daily oral doses of 25 mg/kg BW for 15 days	No toxic signs	EPA 1980

Fed diets containing 35 mg/kg *trans*-chlordane for 78 weeks	No adverse effects on liver	NRCC 1974
Daily oral dose of 50 mg technical chlordane per kilogram BW for 15 days	2 of 5 rats died; toxic signs in survivors	WHO 1984
83–392 mg/kg BW	Acute oral LD50 for *cis*-chlordane	EPA 1980, 1988
Fed diets containing 100 or 200 mg/kg ration of *cis*-chlordane or *trans*-chlordane for 11–15 days	Maximum residues, in mg/kg lipid, in females fed 100 mg/kg *cis*-chlordane were 23 for *cis*-chlordane and 100 for oxychlordane; for the 200 *cis*-chlordane group, levels were 48 for *cis*-chlordane and 182 for oxychlordane. Females fed 100 mg/kg *trans*-chlordane had 10 mg/kg lipid of *trans*-chlordane and 201 of oxychlordane; for the 200 mg/kg group, residues were 23 mg/kg lipid of *trans* chlordane and 470 of oxychlordane; for all groups, residues in males were x6–21 lower than in females	Nomeir and Hajjar 1987
Fed diets averaging 121 and 241 mg/kg feed (females) and 203 and 407 mg technical chlordane per kilogram diet (males) for 80 weeks	Increased mortality, tremors, growth reduction; elevated incidence of thyroid neoplasms and malignancies in all treated animals, but no hepatocellular carcinomas	IARC 1979; EPA 1988
137 mg/kg BW	Acute oral LD50 for rats fed a low protein diet	EPA 1980
200–590 mg technical chlordane per kilogram BW	Acute oral LD50 WHO 1984	NRCC 1975; EPA 1980;
205 mg technical chlordane per kilogram BW	Acute dermal LD50 for females	WHO 1984
Fed diets containing 300, 500, or 1,000 mg technical chlordane per kilogram	75% dead at 300 mg/kg diet after 100 days; all dead in 70 days at 500 mg/kg, or in 10 days at 1,000 mg/kg	WHO 1984
311 mg/kg BW	Acute oral LD50 for rats fed a normal protein diet	EPA 1980
Fed diets containing 320 mg technical chlordane per kilogram from weaning	Reduced sexual activity, reduction in number of viable litters, increase rate of death of progeny before weaning	WHO 1984
327 mg *trans*-chlordane per kilogram BW	Acute oral LD50	EPA 1980; WHO 1984
335 mg/kg BW	Acute oral LD50 for males	IARC 1979
343 mg/kg BW	Acute intraperitoneal (IP) LD50 for adults	EPA 1980
350 mg/kg BW	IP injection produced mild tremors and disorientation within a few minutes, and death within 60 min	EPA 1980
530–690 mg/kg BW	Acute dermal LD50 for females	EPA 1980; WHO 1984
539 mg/kg BW	Acute IP LD50 for newborns pretreated with 40 mg/kg BW phenobarbitol	EPA 1980
840 mg/kg BW	Acute dermal LD50 for males	EPA 1980
1,121 mg/kg BW	Acute IP LD50 for newborns	EPA 1980
Oral administration, in mg/kg BW, of 4,600	Less than 50% dead	WHO 1984

chlordene, 4,600 3-chlorochlordene, 4,600 1-hydroxychlordene, 4,600 chlordene epoxide, 4,600 1-hydroxy, 2, 3-epoxy chlordene, or 10,200 2-chlorochlordene		
Pig, *Sus* spp.		
Fed diet containing 300 mg/kg of *cis*-chlordane or *trans*-chlordane for 60–90 days	Residues of total chlordanes in fat ranged from 9 mg/kg to 72 mg/kg; values were highest for *trans*-chlordane and lowest for *cis*-chlordane	NRCC 1975

Chlordane tends to accumulate in adipose tissues and, to a lesser extent, in liver (Table 5). In general, animals given a single oral dose of chlordane eliminated 80 to 90% of the dose within 7 days, usually by way of the feces; the *cis* isomer is eliminated more rapidly than the *trans* isomer and results in preferential accumulations of *trans*-chlordane (Nomeir and Hajjar 1987). In rats, *trans*-chlordane is rapidly absorbed and distributed to liver and kidney at single oral dosages as low as 0.05 mg/kg BW Ohno et al. 1986). Rabbits fed *trans*-chlordane for 10 weeks excreted 70% of accumulated chlordane during the following 2 weeks on a chlordane-free diet (Menzie 1974). Treatment with *trans*-chlordane resulted in a greater percentage of oxychlordane in fat than did treatment with *cis*-chlordane. When chlordane was removed from the diet of treated animals, levels in fat declined 60% at a relatively steady rate over 4 weeks, but then only slightly thereafter; accumulations in liver, kidney, brain, and muscle were much lower than in fat, but excretion kinetics were similar (Nomeir and Hajjar 1987).

Results of chronic feeding studies show that dietary concentrations of chlordane between 0.76 and 5 mg/kg ration did not affect survival but did produce adverse effects on various species of laboratory animals and livestock (Table 5). Dietary concentrations of 0.76 mg/kg (equivalent to 0.09 mg/kg BW daily) were associated with enlarged livers in mice, 1.0 mg/kg produced elevated residues in cow's milk, 2.5 mg/kg resulted in liver pathology in rats, 3 mg/kg (equivalent to 0.075 mg/kg BW daily) produced high residues in fat of dogs, and 5 mg/kg caused liver pathology in mice (Table 5).

Negative results for mutagenicity of *cis*-chlordane and *trans*-chlordane were reported in various strains of bacteria and in hepatocyte cultures of small mammals. But technical chlordane proved mutagenic to selected strains *of Salmonella typhimurium* and induced gene conversions in certain strains of the yeast *Saccharomyces cervisiae* (IARC 1979; EPA 1980, 1988; WHO 1984).

Chlordane interacts with other chemicals to produce additive or more than additive toxicity. For example, chlordane increased hepatotoxic effects of carbon tetrachloride in the rat (EPA 1980; WHO 1984), and in combination with dimethylnitrosamine acts more than additively in producing liver neoplasms in mice (Williams and Numoto 1984). Chlordane in combination with endrin, methoxychlor, or aldrin is additive or more-than-additive in toxicity to mice (Klaassen et al. 1986). Protein deficiency doubles the acute toxicity of chlordane to rats (WHO 1984). In contrast, chlordane exerts a protective effect against several organophosphorus and carbamate insecticides (WHO 1984) protects mouse embryos against influenza virus infection and mouse newborns against oxazolone delayed hypersensitivity response (Barnett et al. 1985). More research seems warranted on interactions of chlordane with other agricultural chemicals.

Recommendations

All use of chlordane was banned in Norway in 1967 (Ingebrigtsen et al. 1984). In August 1975, EPA issued its intent to suspend registrations and prohibit production of all pesticides containing heptachlor or chlordane, based on evidence of carcinogenicity (Glooschenko and Lott 1977). On 1 July 1983, chlordane use was prohibited in the United States for any purpose except to control underground termites; a similar situation exists in Japan (Ohno et al. 1986; Tojo et al. 1986).

The continued use of chlordane, coupled with its general persistence in the environment, suggests that extreme caution be taken in all stages of its manufacture, transport, storage, and application (Greenhalgh 1986).

In particular, chlordane use near marine environments is not recommended because of chlordane's high toxicity to marine life (EPA 1988). At elevated risk of chlordane toxicity in the human population are children, as a result of the milk they consume; fisherman and their families, because of high consumption of fish and shellfish; people living downwind from fields treated with chlordane; and individuals residing in houses treated with chlordane-containing pesticides (EPA 1980).

The proposed criterion for marine life protection of 0.004 µg/L as a 24-hour mean, not to exceed 0.09 µg/L at any time (Table 6), seems to offer a reasonable degree of protection. But the proposed freshwater criterion of 0.0043 µg/L 24-hour average, not to exceed 2.4 µg/L at any time (Table 6), overlaps the range of 0.2 to 3.0 µg/L, shown earlier to be harmful to sensitive species of fish and aquatic invertebrates; accordingly, the maximum permissible freshwater value should be adjusted downward. "Safe" residues in tissues of aquatic biota require clarification, and probably additional research effort. Criteria on chlordane for protection of mammalian wildlife are missing, and those formulated for birds are incomplete and require data on no-observable-effect levels from lifetime exposures (Table 6). Until this information becomes available, it seems prudent to use criteria developed for human health protection as temporary guidelines for the protection of vertebrate wildlife. Specifically, daily intake should not exceed 0.001 mg total chlordane, including chlordane, *trans*-chlordane, and oxychlordane per kilogram BW; and food items should not exceed 0.3 mg/kg FW (Table 6).

Table 6. Proposed chlordane criteria for protection of natural resources of human health.

Resource	Criterion or effective chlordane concentration	Reference[a]
Aquatic life		
Water concentration, safe level		
Fresh water	<0.0043 ug/L, 24-h average; not to exceed 2.4 ug/L at any time	1
Salt water	<0.004 µg/L, 24-h average; not to exceed 0.09 ug/L at any time	1
Tissue concentrations		
Fish		
Reduced survival	>300 mg/kg tissue, lipid weight (LW) basis	2
No observed adverse effect level (NOEL)	<0.1 mg/kg fresh weight (FW) tissue	3
Estuarine invertebrates, lethal	>106 mg/kg tissue LW	2
Birds		
Concentration in brain		
Joint lethal range	1.1–5.5 mg/kg FW for oxychlordane and 3.4–8.3 mg/kg FW for heptachlor epoxide	4, 12
Single lethal range	6 mg/kg FW for oxychlordane or 9 mg/kg FW for heptachlor epoxide	4, 12
Diet, acceptable range, but producing slight elevation in tissue concentrations	0.1–0.3 mg/kg diet	6
Mammals		
Dog, *Canis familiaris*, NOEL	<3 mg/kg diet, equivalent to <0.075 mg/kg body weight (BW) daily	5, 6
Rat, *Rattus* sp., NOEL	<5 mg/kg diet, equivalent to 0.25 mg/kg BW daily	5
Livestock water use, United States	<3 ug/L	

Human health		
Drinking water		
Worldwide	<0.3 ug/L	5
Canada, United States	<3.0 ug/L	1, 7
Chronic, child, United States	<0.5 ug/L	7
Maximum 1-day exposure, adult, USA	63.0 ug/L	7
Increased lifetime risk of cancer, 70-kg adult, 2 L daily[b]		
10^{-4}	2.7 ug/L	7
10^{-5}	0.27 ug/L	7
10^{-6}	0.027 ug/L	7
Acceptable daily intake[e] 70-g adult	<70 ug, equivalent to <0.001 mg/kg BW	1, 3, 5, 6, 8
Diet		
U.S. Food and Drug Administration "action level"	0.3 mg/kg FW	3, 8, 9, 10
Australia	<0.05 mg/kg FW in meats, including oxychlordane	11
Worldwide	Usually <0.3 mg/kg FW, but residue tolerances vary between 0.02 and 0.5 mg/kg FW, based on the sum of *cis*-chlordane, *trans*-chlordane, and oxychlordane	5, 8
Air		
USSR	Maximum allowable concentration of 0.01 mg/m^3	5
Romania	<0.3 mg/m^3, maximum allowed is 0.6 mg/m^3	5
Belgium, Finland, United States, Japan, the Netherlands	<0.5 mg/m^3	1, 5, 7, 8
15-min exposure limit, United States	<2 mg/ m^3	1

[a] 1. EPA 1980; 2. Zitko 1978; 4. Blus et al. 1983; 5. WHO 1984; 6. NRCC 1975; 7. EPA 1988; 8. IARC 1979; 9. 1965; 10. Wood et al. 1986; 11. Petterson et al. 1988; 12. Stickel et al. 1979.

[b] One excess cancer per million (10^{-6}) is associated with lifetime exposure to chlordane in drinking water at concentrations as low as 0.027 µg/L, the most conservative estimate. A lifetime health advisory computation was not possible because chlordane is a probable human carcinogen (EPA 1988).

[c] Consumed fish are considered to be the only source of chlordane; up to 98% of chlordane exposure results from aquatic organisms with high top (up to 14,100 times) bioconcentration potential (EPA 1980). Urban residents should not consume more than 8 ounces (227 g) of dish daily containing 0.03 mg total chordanes per kilogram FW, and nonurban residents up to 1, 135 mg of fish daily containing 0.03 mg/kg FW (Arruda et al. 1987). The value of 0.001 mg/kg BW is based on the no-observed-effect level of 5 mg/kg in the diet of the rat, equivalent to 0.25 mg/kg BW, and 3 mg/kg in the diet of the dog, equivalent to 0.075 mg/kg BW (WHO 1984).

Additional research on chlordane is recommended in nine general areas: (1) monitoring of background concentrations of oxychlordane in wildlife, since this metabolite is more toxic and persistent than the parent chemical (Kawano et al. 1988); (2) interpretation of the biological significance of residue levels found in wildlife; (3) adoption of improved uniform methods of quantitation so that residue levels can be compared, and so that a time estimate of their environmental significance can be made (NRCC 1975; EPA 1988); (4) reexamination of aquatic toxicity data where concentrations tested exceeded the solubility of chlordane in water of 6 to 9 µg/L (WHO 1984); (5) evaluation of interaction of chlordane with other agricultural chemicals, including heptachlor, to clearly delineate any additive, synergistic, or antagonistic effects (WHO 1984); (6) reevaluation of the cancer risk of chlordane to experimental animals (WHO 1984); (7) measurement of chronic exposures of fish and wildlife to realistic environmental levels (WHO 1984); (8) measurement of effects of depleted soil fertility from chlordane-induced earthworm suppression on migratory birds and other wildlife (NRCC 1975; WHO 1984); and (9) continuance of epidemiological studies on workers who have been exposed to chlordane (WHO 1984).

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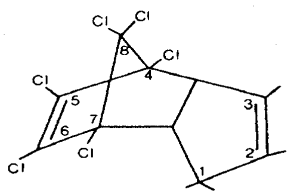

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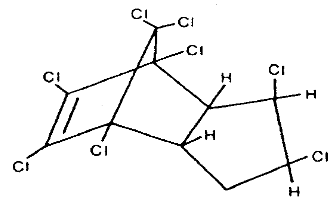

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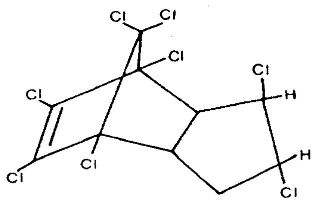

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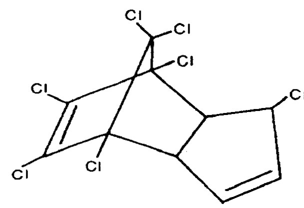

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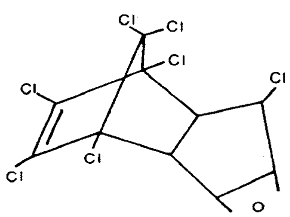

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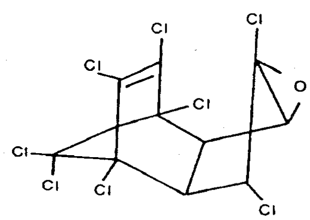

Figure. Chemical structure of chlordane-related compounds:

1. chlordene (4, 5, 6, 7, 8, 8-hexachloro-3a, 4, 7, 7a-tetrahydro-4, 7-methanoindene)

2. *cis*-chlordane, also known as *alpha*-chlordane (1-*exo*, 2-*exo*, 4, 5, 6, 7, 8, 8-octachloro-2, 3, 3a, 4, 7, 7a, hexahydro-4, 7-methanoindene)

3. *trans*-chlordane, also known as *gamma*-chlordane (1 -*exo*, 2-*endo*, 4, 5, 6, 7, 8, 8-octachloro-2, 3, 3a, 4, 7, 7a-hexahydro-4, 7-methanoindene)

4. heptachlor (1, 4, 5, 6, 7, 8, 8-heptachloro-3a, 4, 7, 7a-tetrahydro-4, 7-methanoindene)—technical heptachlor contains about 15 % *cis*-chlordane and 2.5% *trans*-chlordane

5. heptachlor epoxide (1, 4, 5, 6, 7, 8, 8-heptachloro-2, 3-epoxy-3a, 4, 7, 7a-tetrahydro-4, 7-methanoindene)

6. oxychlordane, also known as octachlor epoxide (1-*exo*, 2-*endo*, 4, 5, 6, 7, 8, 8-octachloro, 2, 3-*exo*-epoxy-2, 3, 3a, 4, 7, 7a-hexahydro-4, 7-methanoindene).