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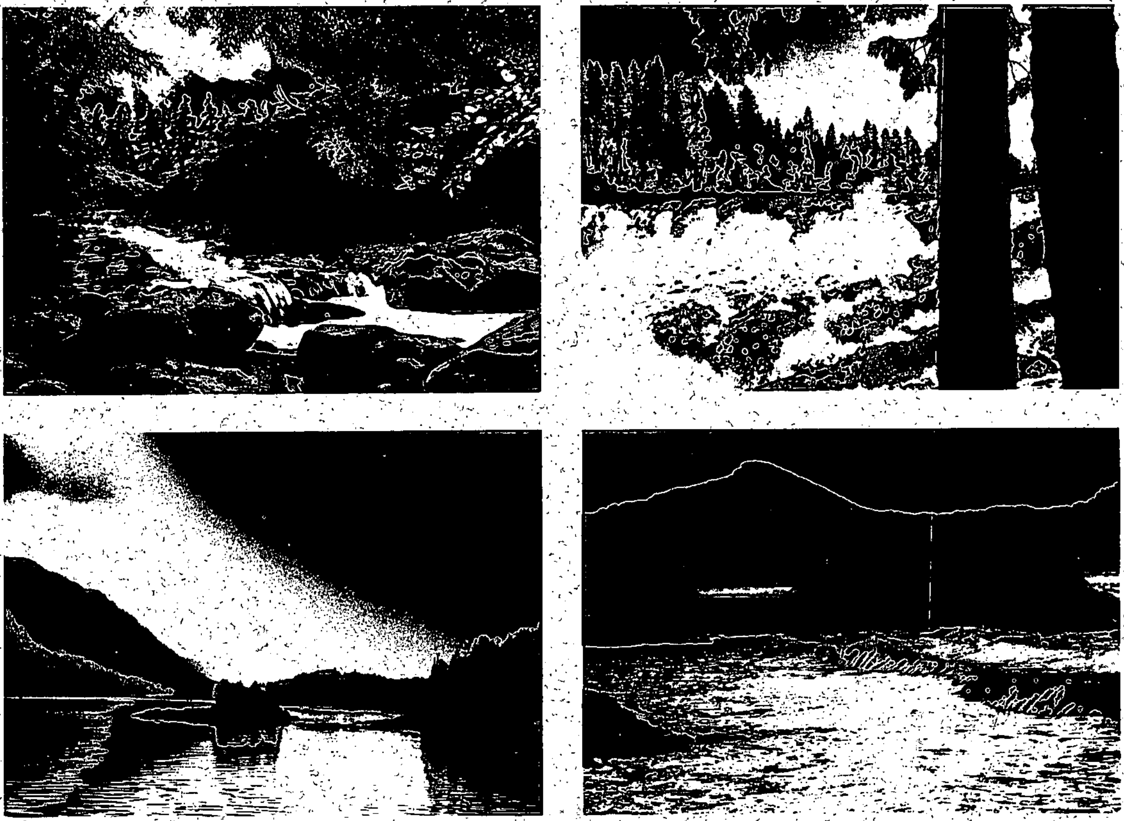

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OTTAWA, ONTARIO, 1992

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Canadian Water Quality Guidelines for Organotins

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Abstract

A literature review was conducted on organotin uses, physical and chemical properties, environmental concentrations, environmental fate and persistence, bioaccumulation potential, toxic effects on freshwater and marine biota, and toxicity to non-target crops and livestock. The information is summarized in this publication. From it, water quality guidelines are recommended for the protection of specific water uses in Canada.

Résumé

On a fait une étude de la documentation sur l'utilisation des organoétains, leurs propriétés physiques et chimiques, leurs concentrations dans l'environnement, leur devenir et leur persistance dans l'environnement, leur potentiel de bioaccumulation, leurs effets toxiques sur l'eau douce et sur le biote marin, et leur toxicité pour les animaux d'élevage et les récoltes non ciblés. On trouvera dans cette publication un résumé de l'information sur le sujet. Cette information a servi à l'élaboration de recommandations pour la protection des utilisations spécifiques de l'eau au Canada.

Preface

Tin has a wide variety of uses as an inorganic metal and in organic compounds. In the past 30 years, organotin compounds have been used in a number of industrial and agricultural applications, including uses as polyvinyl chloride stabilizers, industrial catalysts, industrial and agricultural biocides, and wood-preserving and antifouling agents. However, toxicological and environmental concerns have led to this group of substances being placed on the *Canadian Environmental Protection Act* (CEPA) Priority Substances List. According to this act, substances on this list must be assessed to determine whether they could have immediate or long-term adverse effects on the environment. The purpose of this report is to develop Canadian water quality guidelines for the organotin substances of environmental concern. These guidelines are designed to ensure the protection and maintenance of the five major water uses in Canada: raw water for drinking water supplies, recreation and aesthetics, freshwater and marine aquatic life, livestock watering and irrigation supplies, and industrial water supplies.

Canadian Water Quality Guidelines for Organotins

D.R.J. Moore, D.G. Noble, S.L. Walker, D.M. Trotter, M.P. Wong, and R.C. Pierce

INTRODUCTION

Organotin compounds are characterized by the presence of at least one covalent carbon–tin bond. In this document, the formula R_nSnX_{4-n} (n = 1–4; R = alkyl or aryl; X = H, OR′, halogen, etc.) is used to symbolize the organotin compounds. Depending on the number of organic substituents, the organotins are classified as mono-, di-, tri-, or tetraorganotins. Organic moieties in organotin compounds include, for example, methyl (Me), butyl (Bu), pentyl (Pe), octyl (Oc), and phenyl (Ph) groups, whereas the associated anions are usually chloride, fluoride, oxide, hydroxide, carboxylate, or thiolate. Alkyltin compounds generally refer to those with unbranched, saturated hydrocarbon side chains (i.e., n-alkyltins). Aryltin compounds typically include phenyl or vinyl moieties (Snoeij *et al.* 1987a).

Published environmental and toxicity levels of organotins have been variously expressed in terms of the concentration of (1) Sn, (2) the alkyl- or aryltin, or (3) the organotin cation and associated anion. In order to compare measured concentrations of organotin compounds in water, sediments, and biota, all data in this document, with the exception of Table 3 and Appendices J, L, and M, have been converted to micrograms of organotin cation per litre or per kilogram. Concentrations in Table 3 are expressed in moles, because the analyte forms of the organotin compounds are unknown.

Uses and Production of Organotins

Synthesis of the first organotin compounds occurred in 1852, but application of these compounds as stabilizers in transformer oils and vinyl plastics did not occur until the 1930s. Commercial use expanded rapidly, and today there are three major areas of organotin compound utilization: (1) heat stabilizers for polyvinyl chloride (PVC) polymers, (2) industrial and agricultural biocides, and (3) industrial catalysts in chemical reactions (Snoeij *et al.* 1987a). The most used organotins in Canada and their major uses are summarized in Table 1. A more complete list of compounds and their uses is given in Appendix A.

The biocidal properties of triorganotins have been recognized since 1954. Tripropyltin, tributyltin (TBT), and triphenyltin compounds have strong fungicidal and bactericidal properties. Bis(tributyltin) oxide is used extensively in wood preservatives, marine antifouling paints, and industrial cooling water disinfectants and for slime control in paper mills (Jones *et al.* 1987). Triphenyltin and tributyltin compounds are toxic to molluscs and have been used to control the gastropod intermediate hosts of human parasitic diseases. Triphenyltin compounds are also important agricultural fungicides because of their specific toxicity to two major plant fungi that infect potatoes and sugar beets (C. Ranger, 1989, Pesticides Directorate, Agriculture Canada, pers. com.). Tricyclohexyltin and triphenyltin compounds are effective against the phytophagous mites and ticks that pose a threat to fruit cultivation (Snoeij *et al.* 1987a).

Table 1. Major Uses of Organotin Compounds in Canada

Compound	Use
Dibutyltin bis(isooctylmercaptoacetate)	Stabilizer for polyvinyl chloride used in siding, eavestroughs, and soffits
Dibutyltin dilaurylmercaptide	Polyurethane foam catalyst; feed additive
Stannous 2-ethylhexoate[1]	Polyurethane foam catalyst
Dibutyltin oxide	Precursor for dibutyltin dilaurate
Dibutyltin diacetate	Catalyst for flexible foams
Dibutyltin dilaurate	Chicken feed additive; catalyst for urethanes; esterification catalyst
Bis(tributyltin) oxide	Slimicide in cooling water towers; biocide for antifouling paint; wood preservative; bactericide in fabrics
Tributyltin fluoride	Biocide for antifouling paint until 1989 in Canada
Tributyltin chloride	Bactericide and fungicide used during leather manufacturing; wood preservative
Tributyltin maleate	Bactericide and fungicide in fabrics, adhesives, and latex emulsions
Tributyltin methacrylate	Biocide for antifouling paints; bactericide and fungicide in fabrics and leather
Dioctyltin maleate	Stabilizer for rigid polyvinyl chloride pipe for potable water supplies
Dioctyltin bis(isooctylmercaptoacetate)	Stabilizer for plastics used in food packaging
Fenbutatin oxide	Acaricide

[1] Not a true organotin as defined in Jones *et al.* 1982

Source: Jones *et al.* 1982, with additional information for C. Ranger, 1989, Pesticides Directorate, Agriculture Canada, Ottawa, pers. com., and R.J. Maguire, 1990, National Water Research Institute Burlington, Ont., pers. com.

Of the many types of organotins used in large quantities in Canada, only dibutyltin dilaurate was manufactured here; the remaining organotins used in Canada were imported (NRCC 1985). In 1981, 1982, and 1983, imports of organotin compounds, except

Table 2. Organotin Products Registered under the Pest Control Products Act, September 1990

Regist. No.	Product name	Marketing type[1]/ Product type[2]
Tributyltin chloride		
15593	BIOSPERSE 219	C / MP
20108	SADOLIN SADOVAC 2384	C / WP
Tributyltin maleate		
14498	ULTRA-FRESH DM-50N GERMISTAT	C / MP
Tributyltin methacrylate		
12900	DURAFRESH DM 40 GERMISTAT	C / MP
21316	INTERSMOOTH HISOL (BFA254-plum, BFA256-pink, BFA259-black)	C / AF
21368	INTERSWIFT BKA007 RED	C / AF
Bis(tributyltin) oxide		
5565	PENTOX PRIMER SEALER WOOD PRESERVER GREEN	D / WP
11331	CCC WOOD PRESERVATIVE	C / WP
12879	SANITIZED BRAND 817	C / MP
12880	SANITIZED BRAND RB-475	C / MP
12891	ULTRA-FRESH UDD CATIONIC GERMISTAT	C / MP
12894	ULTRA-FRESH UDD NONIONIC GERMISTAT	C / MP
12895	ULTRA-FRESH 300 DD CATIONIC GERMISTAT	C / MP
12896	ULTRA-FRESH U NONIONIC GERMISTAT	C / MP
12897	ULTRA-FRESH 300 DD CATIONIC GERMISTAT	C / MP
12901	ULTRA-FRESH 300 NONIONIC GERMISTAT	C / MP
12902	ULTRA-FRESH 300 CATIONIC GERMISTAT	C / MP
12904	ULTRA-FRESH U CATIONIC GERMISTAT	C / MP
13189	DEARCIDE 717 COOLING WATER MICROBISTAT	C / SL
13350	DEARCIDE 703 COOLING WATER MICROBISTAT	C / SL
13486	BETZ SLIMICIDE J-12	C / SL
13488	MOGUL AG-471	C / SL
13500	FORMULA 3475	C / SL
13503	VIRGINIA ALGAE-CIDE NO.5	C / SL
13538	SANITIZED BRAND OA-P	C / MP
13778	ALCHEM 4135 FUNGICIDE SAP STAIN INHIBITOR	C / WP
13931	DEARCIDE 700 COOLING WATER MICROBISTAT	C / SL
14565	BIOSPERSE 201	C / SL
14592	MOGUL AG-472	C / SL
15515	ALCHEM 7328	C / SL
15525	ML-15	C / SL
15935	WOLMAN OUTDOOR WOOD END CUT PRESERVATIVE	D / WP
16145	ULTRA-FRESH SN GERMISTAT	C / MP
16585	ML-17 LIQUID FOR CONTROL OF BACTERIA & FUNGI	C / SL
16708	WOOD PRESERVATIVE CLEAR	D / WP
16795	WEATHER SCREEN 704	D / WP
16796	WEATHER SCREEN 707	D / WP
16797	WEATHER SCREEN 709	D / WP
16798	WEATHER SCREEN 713	D / WP
16799	WEATHER SCREEN 716	D / WP
16800	WEATHER SCREEN 717	D / WP
16801	WEATHER SCREEN 723	D / WP
16802	WEATHER SCREEN 726	D / WP
16803	WEATHER SCREEN 911	D / WP
16804	WEATHER SCREEN 913	D / WP
18077	TBTO	M
18129	FORMULA 3470	C / SL
18972	OSMOSE END CUTS WOOD PRESERVATIVE	D / WP
19050	PENTOX ALL WEATHER WOOD PRESERVATIVE FOR CUTS	D / WP
19195	TBTO	M
19539	PILT PLUS GC-447 CONDUCTIVE CONCENTRATE	C / WP
19540	PILT GC-448 NON-CONDUCTIVE CONCENTRATE	C / WP
19541	PILT GC-446 CONDUCTIVE CONCENTRATE	C / WP
19543	PILT PLUS GC-449 NON-CONDUCTIVE CONCENTRATE	C / WP
19591	PITTSBURGH PAINTS EXTERIOR STAIN & WOOD	D /WP
19775	GC-445 RTU NON-CONDUCTIVE PILT WOOD	C / WP
20572	SUPERSYSTEM WOLMAN END CUT PRESERVATIVE	D / WP
21316	INTERSMOOTH HISOL (BFA254-plum, BFA256-pink, BFA259-black)	C / AF
21368	INTERSWIFT BKA007 RED	C / AF
Fenbutatin oxide		
16162	SHELL VENDEX 50W MITICIDE	C / AC
16309	VENDEX 50W MITICIDE	C / AC
17202	PLANT PROD MITE ELIMINATOR	D / AC
17866	VENDEX 50W	C / AC
18594	TECHNICAL FENBUTATIN OXIDE (VENDEX MITICIDE)	M / AC

[1]Marketing types:

C	Commercial
D	Domestic
M	Manufacturing

[2]Product types:

AC	Acaricide
AF	Antifoulant
MP	Material preservative
SL	Slimicide
WP	Wood preservative

bis(tributyltin) oxide, were reported to be 296, 287, and 997 t, respectively. Imports of bis(tributyltin) oxide were 30 and 12 t in 1981 and 1982, respectively (Statistics Canada 1983, 1984). More recent information on organotin consumption is not available, so current trends cannot be estimated. Unpublished information on organotin antifoulants indicates that import and use of organotins as antifoulants have been reduced during the past 2 years as a result of regulatory actions under the Pest Control Products Act.

Dibutyltin bis(isooctylmercaptoacetate), the most widely used organotin in Canada, is utilized for the manufacture of polyvinyl chloride products (an estimated 80%–82% of Canadian organotin use). Additional uses of organotin compounds include use as catalysts (16%–17%) and as biocides (2%–3%).

Several products containing organotins are registered as pesticides under the *Pest Control Products Act* (Table 2). Active ingredients in these products include tributyltin chloride, tributyltin maleate, tributyltin methacrylate, bis(tributyltin) oxide, and fenbutatin oxide. Registered uses include uses as wood preservative (bis(tributyltin) oxide, tributyltin chloride), material preservative (bis(tributyltin) oxide, tributyltin methacrylate, tributyltin chloride, tributyltin maleate), slimicide (bis(tributyltin) oxide), antifoulant (bis(tributyltin) oxide, tributyltin methacrylate), and acaricide (fenbutatin oxide).

Review of Existing Guidelines and Legislation

In Canada, organotins have been on the Priority Chemicals List, Category III, since the *Environmental Contaminants Act* came into force on 1 April 1976. This category is reserved for substances for which further information is required on occurrence, persistence, and toxicity in order to make environmental and human health risk assessments (Environment Canada/Health and Welfare Canada 1979). Toxicological concerns have led to this group of substances being placed on the *Canadian Environmental Protection Act* (CEPA) Priority Substances List (Canada Gazette 1989). According to this act, substances on this list must be assessed to determine whether they could have immediate or long-term adverse effects on the environment.

As administrator of the *Pest Control Products Act*, Agriculture Canada regulates all biocidal uses of organotins. On 12 February 1987, Agriculture Canada formally announced the requirement to register all antifouling paints (Agriculture Canada 1987a). The regulatory status of organotins was addressed further by Agriculture Canada (1987b, 1989, 1990). Use of paints containing tributyltin is prohibited on vessels less than 25 m in length with the exception of those with aluminum hulls. A maximum tributyltin cation release rate of 4 $\mu g \cdot cm^{-2} \cdot d^{-1}$, as determined in standardized laboratory tests, was adopted. These Canadian requirements are similar to those adopted by the U.S. Environmental Protection Agency (EPA) on 16 June 1988 (Federal Register 1988). In Canada, all sales of unregistered antifoulants were terminated on 16 June 1989, whereas use of unregistered products was banned on 31 December 1989. No organotins are being registered for aquaculture and related uses (e.g., nets, lobster traps).

The U.S. EPA has proposed water quality criteria for tributyltin for the freshwater and marine environments (U.S. EPA 1987a, 1987b; Federal Register 1989). Freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-d average concentration of tributyltin does not exceed 0.026 $\mu g \cdot L^{-1}$ more than once every 3 years on the average, and if the 1-h average concentration does not exceed 0.149 $\mu g \cdot L^{-1}$ more than once every 3 years on the average. The corresponding values for the marine environment are 0.01 and 0.266 $\mu g \cdot L^{-1}$, respectively. The U.S. EPA found that there was insufficient information to prepare criterion documents for the remaining organotin compounds. Although many European countries have adopted restrictions on the use of organotin antifoulants, few have water quality guidelines. For marine water, the United Kingdom adopted an Environmental Quality Target of 20 $ng \cdot L^{-1}$ tributyltin in 1985 and an Environmental Quality Standard of 2 $ng \cdot L^{-1}$ tributyltin in 1989 (Abel *et al.* 1987; Cleary 1990). Water quality guidelines for organotins have not previously been prepared for Canadian freshwater and marine environments.

PHYSICAL AND CHEMICAL PROPERTIES

General Properties

The physical and chemical properties of organotins vary widely according to the numbers and types of organic and inorganic moieties bonded to the tin atom. Although not a complete list, Appendix A presents the physical and chemical properties of 110 organotin compounds. In general, the solubility of organotin compounds ranges from 5 to 50 $mg \cdot L^{-1}$ (Eisler 1989). The larger the number and molecular weight of the organic groups attached to the tin atom, the lower the compound's solubility in water and the higher its solubility in octanol (NRCC 1985). The octanol/water partition coefficients for high-molecular-weight organotins suggest a potential for bioaccumulation. The presence of chloride in seawater reduces the solubility of tributyltin and triphenyltin compounds, probably by associating with the hydrated cation to form the covalent organotin chloride (Blunden *et al.* 1985). Most commercially used organotins are characterized by low mobility in the aquatic environment as a result of low aqueous solubility, low vapour pressure, and a high affinity for aquatic sediments (Blunden and Chapman 1982).

Methods of Analysis

Analytical methods for organotin compounds relevant to the aquatic environment are summarized in Table 3. Minimum detectable concentrations are in the range of 10^{-7}–10^{-16} mol tin, depending on the compound, the medium, and the technique used. For example, the National Water Research Institute in Burlington, Ont., uses the following procedure to analyze for butyltin species: (1) extract the butyltin species (tri-, di-, and monoorganotin, and inorganic tin) from water samples or dry sediments with the complexing agent tropolone dissolved in benzene, (2) pentylate

Table 3. Summary of Techniques for Analysis of Organotin Compounds

Technique[1]	Analyte form	Detection limit (Sn)[2]
Spectrophotometry	R_2SnQ_2, R_3SnQ	10^{-9}–10^{-7} mol•L^{-1}
Spectrofluorimetry	R_nSnQ_{4-n}, Ph_3SnQ (R = Me, Et, Pr, Bu)	10^{-9}–10^{-7} mol•L^{-1}
ASV	Ph_3SnQ $BuSnCl_3$, $OcSnCl_3$, $SnCl_4$	10^{-8} mol•L^{-1} 3 × 10^{-7} mol•L^{-1}
GC–ECD	R_3SnQ, R_4Sn (R = Et, Pr, Bu)	8.4 × 10^{-15} – 8.4 × 10^{-11} mol
GC–FPD	R_nSnH_{4-n} (R = Me, Ph, Bu)	4.2 × 10^{-13} mol
GC–FPD modified	Pr_4Sn	3.36 × 10^{-16} mol
GC–AAS	Me_nSnBu_{4-n}	8.4 × 10^{-13} mol
GC–emission	Me_nSnH_{4-n}	8.4 × 10^{-14} mol
GC–plasma	Et_nSnPr_{4-n}	5.04 × 10^{-14} mol
GC–MS	Bu_nSnMe_{4-n}	1.68 × 10^{-12} mol
GC–FID	R_4Sn (R = Et, Pr, Bu)	8.4 × 10^{-12} mol
LC–AAS	R_nSnH_{4-n} (R = Me, Et)	8.4 × 10^{-14} mol
LC–AAS	R_nSnQ_{4-n} (R = aryl, alkyl, alicyclic)	2.52 × 10^{-12} – 4.2 × 10^{-11} mol
TLC–AAS	Bu_3SnQ, Ph_3SnQ	1.68 × 10^{-9} mol

[1] Abbreviations are as follows: ASV, anodic stripping voltammetry; ECD, electron capture detector; GC, gas chromatography; FPD, flame photometric detector; AAS, atomic absorption spectometry; MS, mass spectrometry; FID, flame ionization detector; LC, liquid chromatography; TLC, thin-layer chromatography; Me, methyl; Et, ethyl; Pr, propyl; Bu, butyl; Oc, octyl; Ph, phenyl; Q is the counterion.

[2] Detection limits are in moles of Sn and are reported as those amounts or concentrations that generate a signal twice the baseline noise.

Source: NRCC 1985.

the extract to produce volatile mixed butylpentyltin derivatives, $Bu_nPe_{4-n}Sn$, (3) clean up the extract by silica gel column chromatography, and (4) concentrate and analyze by packed-column gas chromatography with either a modified flame photometric detector (GC–FPD modified) or a quartz tube furnace atomic absorption spectrophotometric detector (GC–AAS) (Maguire 1989). Seakem Oceanography Ltd. used a gas chromatograph/mass spectrometer (GC–MS) to determine butyltin levels in water, sediment, and oyster tissue samples collected from Nanoose Bay, B.C. (Harding and Kay 1988). In the Harding and Kay (1988) study, the tributyltin detection limits were 0.1 ng•L^{-1}, 0.07 ng•kg^{-1}, and 1.0 ng•kg^{-1} as tin in water, sediments, and tissue samples, respectively.

ENVIRONMENTAL CONCENTRATIONS

Sources and Pathways for Entering the Aquatic Environment

Little information exists regarding the quantities of organotins entering the aquatic environment in Canada from processing, use, and disposal activities. Entry of fenbutatin oxide that is used in crop protection in Canada into surface water environments is not considered significant because of its limited usage, its strong adsorption to soil particles, and a high air dilution factor (Bock 1981; NRCC 1985; R.J. Maguire, 1990, National Water Research Institute, Burlington, Ont., pers. com.). Although the major use of organotins in Canada is for heat stabilization of products containing polyvinyl chloride, the greatest potential for direct input to the aquatic environment is from direct organotin usage as biocides in water. Several organotin compounds are routinely used in paints as preservatives against water damage and fouling biological growths on exposed underwater surfaces. The widespread use of organotin-based antifouling paints on boat hulls and to protect lobster traps and fishing nets has resulted in elevated concentrations of these compounds in freshwater, estuarine, and marine environments (Maguire *et al.* 1982, 1985, 1986; Maguire 1984, 1986; NRCC 1985; Anderson and Dalley 1986; Bailey 1986; Champ 1986; Laughlin and Linden 1987; Clark *et al.* 1988). Mandatory registration of antifoulants under the Pest Control Products Act has resulted in reductions in the volume of use of organotins as antifoulants and in the banning of their use on nets and on lobster traps.

The amount of organotins entering the environment in the United States in 1976 was estimated to be 4775 t, primarily from landfills. Approximately 91 t of triorganotin biocides per year are part of the total organotins entering the environment (Laughlin and Linden 1985).

The U.S. Navy has determined that the release rate of tributyltin from antifouling paints on ships is dependent upon (1) the chemistry of the coating, (2) the environmental chemistry (particularly temperature, pH, and salinity), (3) flow rate and turbulence, (4) the extent of biological activity, and (5) the age of the paint film (Champ and Bleil 1988). The release rate of tributyltin from ship hulls to the water is estimated by laboratory studies to range from <0.1 to 1.9 $\mu g \bullet cm^{-2} \bullet d^{-1}$. *In situ* tribulyltin release rates from U.S. Navy ship hulls have been determined to range from 0.33 to 2.8 $\mu g \bullet cm^{-2} \bullet d^{-1}$, depending on the paint formula and the location of the ships (Lieberman *et al.* 1985). However, paints with higher release rates were used on recreational craft (approximately 5 $\mu g \bullet cm^{-2} \bullet d^{-1}$) because of their cheaper costs (Champ and Bleil 1988). Based on a total wetted hull surface of 3.99×10^8 cm^2 in a study carried out in Norfolk Harbor, Va., a mean leach rate of 1.0 $\mu g \bullet cm^{-2} \bullet d^{-1}$ is equivalent to a tributyltin loading to the water column of 390 $g \bullet d^{-1}$ (Pollman and Chou 1987). This loading rate would lead to a predicted steady-state concentration of between 0.05 and 0.2 $\mu g \bullet L^{-1}$ tributyltin in Norfolk Harbor waters.

The United States has approximately 15 million small recreational boats, 68 000 pleasure yachts, and 87 000 commercial vessels, with a total surface area of 440 million square feet requiring antifouling paint. The U.S. Navy has an additional 11 million square feet of bottom hull surface area (Champ and Bleil 1988). In the Atlantic provinces of Canada, a 1986/1987 survey identified a total of 3.44 t of tributyltin in use in the region (Kieley 1989). Of this total, 53% (1.725 t) was used in antifoulant paints and 24% (0.84 t) was used as lobster trap preservative. Comparable estimates of organotin uses in the aquatic environment are not available for the rest of Canada. This research gap needs to be filled in order to estimate the risks of exposure of aquatic biota to tributyltin in Canada.

Concentrations in Water, Sediments, and Biota

Methyltins

Methyltin compounds, which result from anthropogenic sources as well as biotic and abiotic methylation of inorganic tin, have been detected in a variety of natural waters, sediments, and biota (NRCC 1985). Appendix B indicates that mono-, di-, and trimethyltins have been found in surface water samples taken from many locations in Canada. The maximum concentrations observed for monomethyltin (1.22 $\mu g \bullet L^{-1}$ in Kingston Harbour), dimethyltin (0.32 $\mu g \bullet L^{-1}$ in Kingston Harbour), and trimethyltin (0.248 $\mu g \bullet L^{-1}$ in Vancouver Harbour) (Maguire *et al.* 1982, 1986) were similar to, or higher than, the levels found in relatively polluted sites, such as Chesapeake Bay (Jackson *et al.* 1982) and the Rhine River (Byrd and Andreae 1982). In general, methyltin concentrations were much higher near harbours, marinas, or areas of industrial activity (e.g., Belleville Harbour, Whitby Harbour, Kingston Harbour, a Lake St. Clair marina, Victoria Harbour, Vancouver Harbour) than in locations without direct anthropogenic inputs (e.g., North Bay, Lake Superior) (Maguire *et al.* 1982, 1986).

To date, few surveys have been taken to determine methyltin levels in sediments in Canada or elsewhere (Appendix C). Tugrul *et al.* (1983) found methyltins, particularly mono- and dimethyltin, at high levels in polluted harbours and estuaries on the northeast coast of the Mediterranean. Maguire *et al.* (1986) conducted a sediment survey of selected harbours, lakes, and rivers in Canada and found that monomethyltin levels were relatively low in Montreal Harbour (23 $\mu g \bullet kg^{-1}$), Lac-St-Louis (11 $\mu g \bullet kg^{-1}$), and Vancouver Harbour (nd–23 $\mu g \bullet kg^{-1}$). However, monomethyltin concentrations in several New Brunswick harbour sediments were higher (up to 19 360 $\mu g \bullet kg^{-1}$) than in the most polluted sites in the Mediterranean Sea (up to 10.6 $\mu g \bullet kg^{-1}$) (Tugrul *et al.* 1983). In the Canadian sediment survey, Maguire *et al.* (1986) found that dimethyltin concentrations ranged from below the detection limit to 200 $\mu g \bullet kg^{-1}$ and trimethyltin concentrations ranged from below the detection limit to 900 $\mu g \bullet kg^{-1}$.

As with sediments, few surveys have been conducted to determine methyltin concentrations in aquatic biota. Appendix D indicates little evidence of biomagnification of methytins in aquatic biota. For example, in the study by Tugrul *et al.* (1983), dimethyltin concentrations ranged from 0.5 to 37 $\mu g \bullet kg^{-1}$ dry weight in marine plants, from 0.2 to 18 $\mu g \bullet kg^{-1}$ dry weight in limpets, and from 2.6 to 2.9 $\mu g \bullet kg^{-1}$ dry weight in fish. The same trend was evident with trimethyltin (Tugrul *et al.* 1983) and tetramethyltin (Seidel *et al.* 1980). In the only survey of methyltin concentrations in Canadian aquatic biota, Chau *et al.* (1984) found that monomethyltin levels in fish from several Lake Ontario harbours ranged from 250 to 990 $\mu g \bullet kg^{-1}$ wet weight. These levels were at least an order of magnitude higher than those found in all other locations worldwide.

Butyltins

Tributyltin compounds occur at high concentrations in water, sediments, and biota associated with harbour locations (Appendices B, C, and D). For example, in the United States, tributyltin concentrations ranged up to 0.16 $\mu g \cdot L^{-1}$ in San Francisco Bay, 0.8 $\mu g \cdot L^{-1}$ in Chesapeake Bay, 1.0 $\mu g \cdot L^{-1}$ in San Diego Bay, and 0.27 $\mu g \cdot L^{-1}$ in Honolulu Harbor (Federal Register 1988). A monitoring study in Chesapeake Bay during the summer of 1986 showed a strong correlation between boat density and observed tributyltin concentrations in four harbours (Federal Register 1988). In 10% of freshwater samples from 265 locations across Canada, tributyltin was found at levels greater than or equal to 0.2 $\mu g \cdot L^{-1}$ (Maguire 1987, 1989). The highest tributyltin concentration reported in Canada was found in Toronto Harbour (43.4 $\mu g \cdot L^{-1}$); however, this value was considered suspect because the sample may have been contaminated with sediment (Maguire 1989).

In Canada, dibutyltin was found in about 10% of all subsurface water samples (Maguire 1989). The presence of dibutyltin in these samples could be the result of either direct inputs from its use as a polyvinyl chloride stabilizer or tributyltin degradation. The latter case is more likely, as dibutyltin was found primarily in areas where tributyltin was found (i.e., harbours, marinas, etc.). Monobutyltin was also found in about 10% of the water samples (0.5 m depth) taken in Canada (Maguire 1989). Appendix B contains data indicating that several Canadian harbour locations are contaminated with mono-, di-, and tributyltin at concentrations similar to those found in the most contaminated sites worldwide (e.g., Chesapeake Bay, Norfolk Harbor, San Diego Bay).

Sediments (top 2 cm) from Vancouver Harbour have been found to contain up to 25 900 $\mu g \cdot kg^{-1}$ dry weight as tributyltin, up to 16 200 $\mu g \cdot kg^{-1}$ dry weight as dibutyltin, and up to 7095 $\mu g \cdot kg^{-1}$ dry weight as monobutyltin (Maguire *et al.* 1986). The butyltin levels found in this harbour and in several other Canadian harbours (e.g., Esquimalt Harbour, B.C.) were at least an order of magnitude higher than the levels found in several of the most contaminated sites worldwide (e.g., Puget Sound, San Diego Bay, Boston Harbor, Hamble River [U.K.]) (Appendix C).

Several studies have shown that bivalve species (e.g., mussels, oysters) accumulate butyltins to levels (e.g., up to 10 800 $\mu g \cdot kg^{-1}$ tributyltin, 1860 $\mu g \cdot kg^{-1}$ dry weight as monobutyltin) that are much higher than those found in fish in similar locations (Maguire 1987; Sasaki *et al.* 1988; Wade *et al.* 1988). As with water and sediments, the highest butyltin concentrations were found in biota associated with harbours (e.g., Harbor Island [California], San Pedro Harbor [California], San Diego Bay, Honolulu Harbor) (Wade *et al.* 1988; Uhler *et al.* 1989). Few studies have been conducted in Canada to determine butyltin levels in aquatic biota. In Vancouver Harbour, tri-, di-, and monobutyltin concentrations of 580, 98, and 90 $\mu g \cdot kg^{-1}$ wet weight, respectively, were found in fish samples (Maguire *et al.* 1986). In Nanoose Bay, B.C., tributyltin concentrations as high as 1800 $\mu g \cdot kg^{-1}$ dry weight were found in oyster tissue samples; at this location, the major source of tributyltin was from salmon nets treated with tributyltin as a marine growth retardant (Harding and Kay 1988).

Other Organotins

Maguire (1984) found tributylmethyltin (Bu_3MeSn) and dibutyldimethyltin (Bu_2Me_2Sn) in the sediments of four harbours in Ontario. However, the occurrence of these compounds was infrequent and was likely the result of methylation of butyltin species in the aquatic environment (Maguire *et al.* 1986). No other organotin compounds (e.g., phenyl, cyclohexyl) have been reported in water, sediments, or biota thus far.

ENVIRONMENTAL FATE AND PERSISTENCE

Tin in its inorganic form is generally accepted as being non-toxic because it is rapidly converted to the insoluble oxide at physiological pH (Blunden and Chapman 1982). However, the attachment of alkyl or aryl groups to the tin atom, via a Sn–C bond, greatly increases the toxic effects on aquatic biota. Sequential introduction of organic groups in any R_nSnX_{4-n} series produces a maximum toxic effect when $n = 3$ (i.e., the triorganotin compounds) (Blunden and Chapman 1982). Therefore, the following discussion of the environmental fate and behaviour of organotins will focus on the triorganotins that may be of environmental significance (i.e., trimethyltin, tributyltin, triphenyltin; see preceding section).

The degradation of an organotin compound may be defined as the sequential removal of the alkyl or aryl groups attached to the tin atom:

$$R_4Sn \rightarrow R_3SnX \rightarrow R_2SnX_2 \rightarrow RSnX_3 \rightarrow SnX_4$$

Thus, the degradation process involves the breaking of a Sn–C bond rather than the breaking of a Sn–X bond. Anion exchange gives a false impression of degradation kinetics when what is significant is the loss of alkyl or aryl groups (Maguire 1987); the nature of the anion has little effect on toxicity (Davies and Smith 1980). The breaking of a Sn–C bond may occur by a number of different processes: (1) ultraviolet irradiation, (2) biologically induced cleavage, (3) chemically induced cleavage, (4) thermally induced cleavage, and (5) gamma irradiation (Blunden and Chapman 1982). Of these processes, thermally induced cleavage is not likely to be of environmental significance because the Sn–C bond is stable at temperatures below 200°C (Zuckerman *et al.* 1978). Similarly, because of the rare occurrence of gamma irradiation at the earth's surface, this process is likely to have a negligible effect on the environmental degradation of organotin compounds (Clark *et al.* 1988).

In addition to the above chemical and biological degradation processes, persistence of organotin compounds may be affected by several physical processes (e.g., volatilization, adsorption to suspended solids and sediments, water flow) (Maguire 1987). Volatilization of the mono-, di-, and triorganotins is likely to be negligible because of the tendency for these compounds to strongly adsorb to suspended solids and sediments (Maguire and Tkacz 1985). Adsorption of organotins to suspended solids and sediments has the potential to be an important mechanism for their removal from the water column because of the high sediment/water partition coefficients of these compounds (e.g., tributyltin K_{oc} = 3370) (Cardwell 1988). However, adsorption to suspended solids and sediments should not be used as the sole definition for removal of organotin compounds from the aquatic environment, as toxic residues could be mobilized through desorption, sediment resuspension, or uptake by benthic biota (NRCC 1985). The following discussion summarizes the available environmental fate and behaviour information for methyltin, butyltin, and phenyltin compounds, with particular emphasis on the degradation processes of ultraviolet irradiation and biologically and chemically induced cleavage.

Methyltins

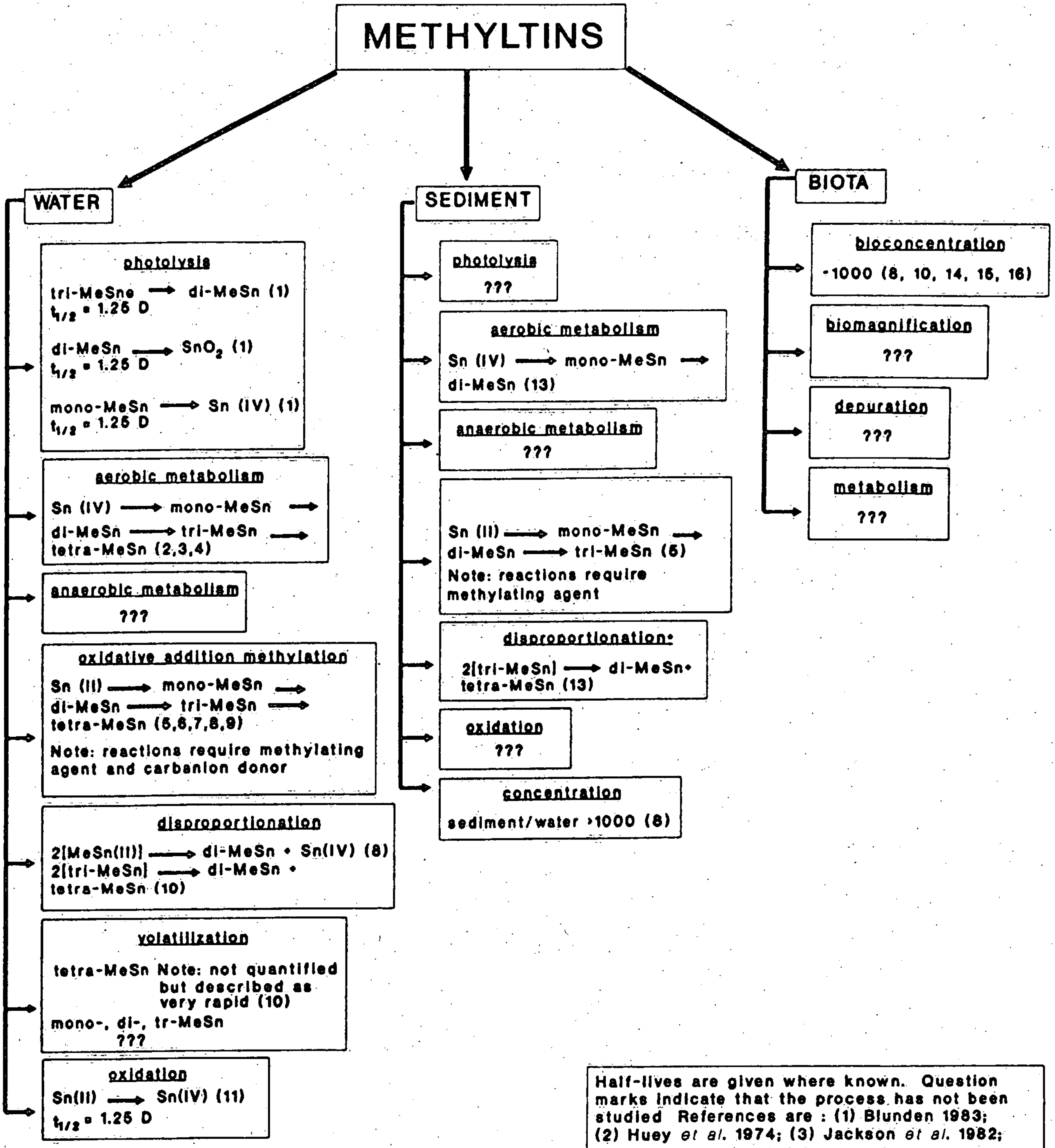
Inorganic tin present in the aquatic environment has the potential to be methylated, producing mono-, di-, tri-, and tetramethyltin compounds that were not previously in the area (Maguire *et al.* 1986). The widespread occurrence of methyltin compounds in the freshwater, estuarine, and marine environments, especially in remote areas, cannot be explained solely in terms of pollution by anthropogenic sources. The natural formation of methyltin compounds can occur by several abiotic and biotic processes (Fig. 1). Aerobic bacterial strains and mixtures have been isolated that can methylate inorganic tin to produce mono-, di-, tri-, and tetramethyltins, both in the water column (Huey *et al.* 1974; Blair *et al.* 1981; Jackson *et al.* 1982) and in water/sediment mixtures (Chau *et al.* 1981; Hallas *et al.* 1982; Gilmour *et al.* 1985). Chau *et al.* (1981) demonstrated that both Sn(II) and Sn(IV) underwent microbial transformation to methyltin compounds in fresh water. Gilmour *et al.* (1985, 1987) demonstrated that several bacterial cultures, most notably sulphate-reducing bacteria isolated from anoxic estuarine sediments, formed mono- and dimethyltin from inorganic tin, both in sediment and when isolated from sediment. Anaerobic methylation of inorganic tin was, however, a slow process, such that only 0.02% of the added inorganic tin was converted to methyltin compounds during a 61-d incubation period (Gilmour *et al.* 1987).

Chemical methylation of inorganic Sn(II) has also been observed in water (Chau *et al.* 1981; Rapsomanikis and Weber 1985; Craig and Rapsomanikis 1985; Rapsomanikis *et al.* 1987; Ring and Weber 1988) and in water/sediment mixtures (Chau *et al.* 1981) (Fig. 1). This reaction requires a methylating agent; a number of these substances are known to be quite common in the aquatic environment. For example, seaweeds and algae release methyl iodide (CH3I) and 3-(dimethylsulphonio) propionate, both of which are capable of donating a positive methyl group (carbocation) to appropriate metal acceptors (Rapsomanikis and Weber 1985). Such a reaction is called oxidative addition. High yields of methyltin compounds have been observed when a carbanion-donating dimethylcobalt complex was included in the above reaction (Rapsomanikis and Weber 1985). Further work by Ring and Weber (1988) indicated that the methylation of Sn(II) was virtually unaffected by salinity.

Disproportionation reactions (reactions involving the redistribution of ligands) can lead to the formation of dimethyltin from two monomethyltin molecules (Ring and Weber 1988) or di- and tetramethyltin from two trimethyltin molecules (Donard *et al.* 1987). Tetramethyltin rapidly volatilizes from the water column, but the importance of this removal process has not yet been quantified (Donard *et al.* 1987).

Ring and Weber (1988) found that methyltin concentrations were over 1000 times greater in sediments and seaweeds than in the water column. This study indicated that these two media may be important sinks for methyltins, although detailed adsorption/desorption studies remain to be done.

No studies were found that documented depuration or metabolism rates of methyltins in aquatic biota. Because the methyltin compounds, particularly trimethyltin, are much more toxic to aquatic biota than is inorganic tin (Laughlin *et al.* 1985a), this information is essential in evaluating the environmental fate profile of methyltins.



Half-lives are given where known. Question marks indicate that the process has not been studied References are : (1) Blunden 1983; (2) Huey *et al.* 1974; (3) Jackson *et al.* 1982; (4) Blair *et al.* 1981; (5) Chau *et al.* 1981; (6) Rapsomanikis and Weber 1985; (7) Craig and Rapsomanikis 1985; (8) Ring and Weber 1988; (9) Rapsomanikis 1987; (10) Donald *et al.* 1981; (11) Fanchiang and Wood 1981; (12) Hallas *et al.* 1982; (13) Guard *et al.* 1981; (14) Seidel *et al.* 1980; (15) Ishii 1982; and (16) Wong *et al.* 1984.

*Medium = water/sediment mixture

Figure 1. Potential fate processes for the methyltins.

Butyltins

The available evidence suggests that microbial degradation is the major breakdown pathway for butyltins in the aquatic environment (Clark *et al.* 1988) (Fig. 2). Numerous studies are available that describe the biodegradation of tributyltin by microorganisms in natural water and sediments and in laboratory cultures (Maguire 1986; Olson and Brinckman 1986; Seligman *et al.* 1986a, 1986b; Sutter and Carey 1986; Walton *et al.* 1986; Lee *et al.* 1987; Hattori *et al.* 1988). Generally, biodegradation of tributyltin proceeds by sequential debutylation to di- and then monobutyltin and ultimately to inorganic tin. Laboratory studies show microbial debutylation to be slower for dibutyltin than for tributyltin. Half-lives for the biodegradation of tributyltin are greatly influenced by site-specific environmental conditions (e.g., temperature, dissolved oxygen, and microbial species composition). In general, half-lives range from 5 to 20 d in marine and estuarine waters (Olson and Brinckman 1986; Seligman *et al.* 1986a; Hattori *et al.* 1988) and from 4 to 5 months in fresh water and in freshwater sediments (Maguire 1986). Tributyltin is considered to be slightly to moderately persistent in water and moderately persistent in sediments (Maguire *et al.* 1986; Lee *et al.* 1987; Hinga *et al.* 1987). Anaerobic degradation appears to be very slow, with half-lives in the range between 1.5 and >12 months (Cardwell and Sheldon 1986; Maguire 1986). There is evidence that anaerobic degradation is faster than aerobic degradation (Maguire 1986).

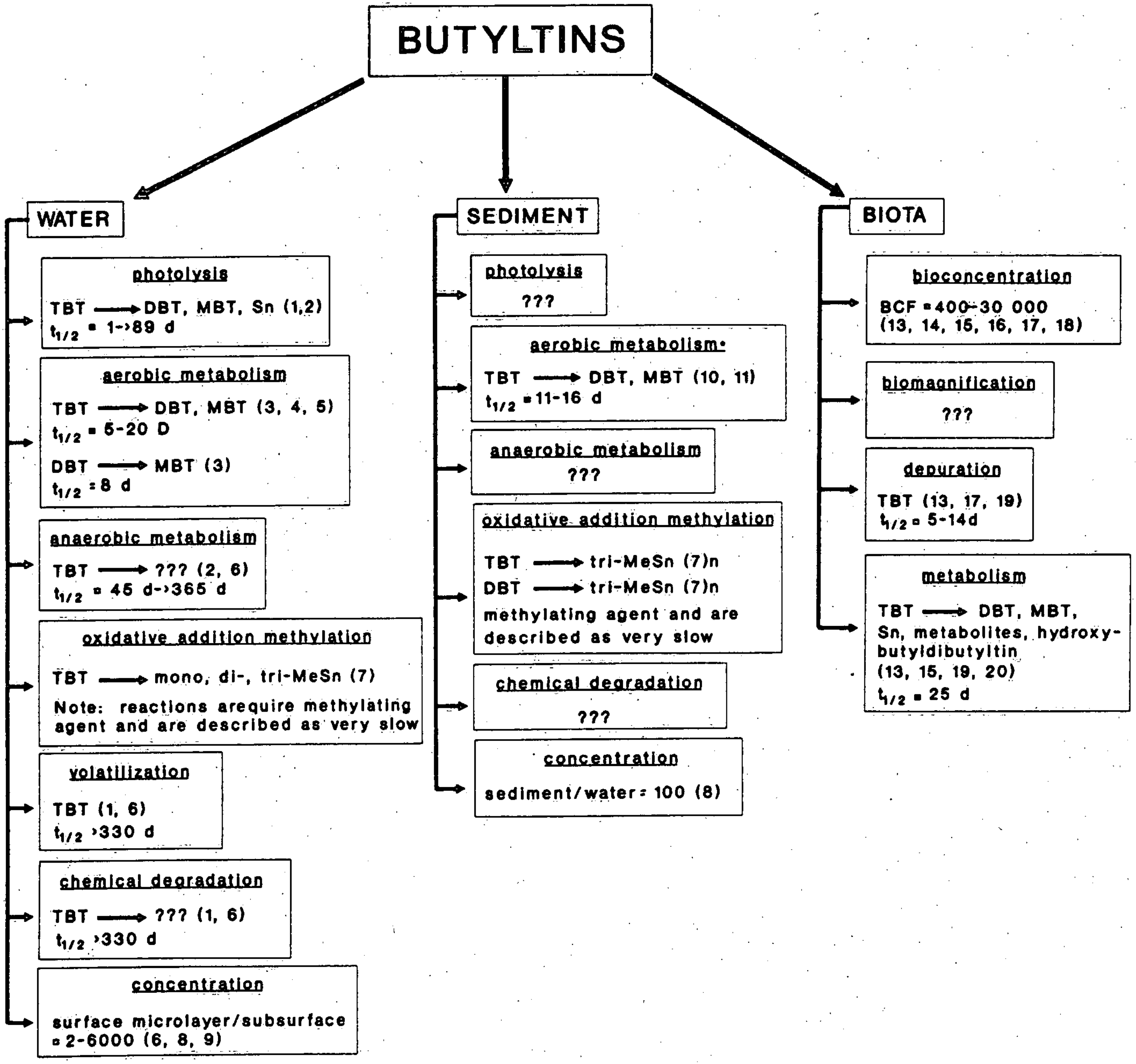
The more rapid degradation of tributyltin in water from marinas suggests that some microbial populations may acquire an enhanced capability for tributyltin degradation or may differ in species composition. High tributyltin concentrations in bays and marinas are associated with high tributyltin degradation rates (Seligman *et al.* 1986a; Lee *et al.* 1987).

Degradation of tributyltin by chemical and photolytic mechanisms appears limited. Chemical degradation in fresh water/sediment mixtures is slow, with half-lives exceeding 11 months (Maguire *et al.* 1983). Removal rates due to volatilization are equally slow (Maguire *et al.* 1983; Maguire 1986). Photolysis has been shown to degrade tributyltin by sequential debutylation, although reported degradation rates are quite variable ($t_{1/2}$ = 1–>89 d) (Maguire *et al.* 1983; Cardwell and Sheldon 1986). Hinga *et al.* (1987) reported photodegradation of tributyltin in mesocosms to be slow and insignificant. Localized conditions (e.g., types and concentrations of naturally occurring photosensitizers, such as fulvic acid) are thought to be responsible for the observed variation. The role photolysis may play in butyltin degradation is not fully understood (Cooney 1988).

Most of the butyltin compounds found in the water column are either dissolved or associated with particles smaller than 0.2 µm in diameter. The variability of results from experiments designed to quantify the partitioning between dissolved and particulate phases is attributed to the physical techniques used to separate the phases, the chemical analyses of the various phases containing the butyltin compounds, and the inherent variability of the composition of suspended particles used (Valkirs *et al.* 1986a, 1987b; Johnson *et al.* 1987). Regardless of the relatively small amount of butyltins associated with the particulate phase in the water column, it is obvious from the concentrations of butyltins reported in surface waters and associated sediments that butyltin concentrations are 2–3 orders of magnitude higher in sediments than in the overlying water (Valkirs *et al.* 1986a). The affinity of butyltins for sediments has been demonstrated experimentally; more than 90% of the tributyltin originally present in the aqueous phase was adsorbed to the sediment, with equilibrium between butyltin dissolved in seawater and sediment achieved in 30 min (Valkirs *et al.* 1986a). Tributyltin dissolved in seawater of approximately pH 8 forms three equilibrium products: tributyltin chloride, tributyltin hydroxide, and a carbonate species (Laughlin *et al.* 1986b). Below pH 7, tributyltin chloride and an aquo complex ($TBTOH_2$+) predominate; at pH 10, the equilibrium shifts to favour the hydroxide and the carbonate species (Laughlin *et al.* 1986b).

Estimated partition coefficients for aqueous tributyltin on sediments or particulate matter are reported to range from 3.4×10^2 to 1.9×10^6, with most of the values in the order of 10^3. Salinity effects on the partition coefficient have been investigated in a laboratory study using hydrous iron hydroxide as the suspended particulate phase in a water/fulvic acid system. This particular simulation showed increased adsorption of tributyltin to suspended particles with increasing salinity (Randall and Weber 1986). This trend was also found in a study of tributyltin adsorption to resuspended sediments in two British estuaries (Harris and Cleary 1987). In contrast, sediments from tidal creeks entering Chesapeake Bay exhibited a linear decrease in adsorption of tributyltin with increased salinity over the range 0–35 $g{\bullet}L^{-1}$ (Unger *et al.* 1987, 1988).

In situ investigations of rates of desorption of tributyltin from estuarine sediment at constant salinity showed that tributyltin did not significantly desorb from the sediment. The corresponding adsorption rate for tributyltin was calculated to be 0.57 $ng{\bullet}cm^{-2}{\bullet}d^{-1}$. However, desorption of dibutyltin from the sediment does occur at rates between 0.16 and 0.55 $ng{\bullet}cm^{-2}{\bullet}d^{-1}$. Adsorption and desorption rates for monobutyltin could not be determined (Stang and Seligman 1987).



Half-lives are given where known. Question marks indicate that the process has not been studied. References are: (1) Maguire *et al.* 1983; (2) Cardwell and Sheldon 1986; (3) Hattori *et al.* 1988; (4) Seligman *et al.* 1986b; (5) Olson and Brinckman 1986; (6) Maguire 1986; (7) Chau *et al.* 1981; (8) Maguire *et al.* 1982; (9) Cleary and Stebbing 1987a; (10) Barug 1981; (11) M&T Chemicals Inc. 1978; (12) Valkirs *et al.* 1986a; (13) Ward *et al.* 1981; (14) Wade *et al.* 1988; (15) Maguire *et al.* 1984; (16) Seidel *et al.* 1980; (17) Laughlin *et al.* 1986b; (18) Martin *et al.* 1989; (19) Lee 1986; and (20) Lee *et al.* 1987.

•Medium = water/sediment mixture

Figure 2. Potential fate processes for the butyltins.

Partitioning of tributyltin into the surface microlayer of natural surface waters is of concern. Although not as intensively studied as sediment partitioning, it is obvious from the sampling and analysis of surface microlayers (see Appendix B) that tributyltin concentrations can be 2–3 orders of magnitude higher in the surface microlayer than in subsurface waters (Maguire *et al.* 1982; Gucinski 1986; Cleary and Stebbing 1987b).

Several freshwater and marine aquatic fish (e.g., *Cyprinodon variegatus*, *Oncorhynchus mykiss*, *Leistomus canthurus*, and *Cyprinus carpio*), invertebrates (e.g., *Penaeus aztecus* and *Callinectes sapidus*), a diatom (*Skeletonema costatum*), and an algae (*Ankistrodesmus falcatus*) have been reported to metabolize tributyltin (Ward *et al.* 1981; Maguire *et al.* 1984; Lee 1986; Lee *et al.* 1987; Tsuda *et al.* 1988; Martin *et al.* 1989). The breakdown products included dibutyltin, monobutyltin, inorganic tin, hydroxybutyldibutyltin, and several polar metabolites. The half-life for tributyltin metabolism in a freshwater green alga (*Ankistrodesmus falcatus*) was reported to be 25 d (Maguire *et al.* 1984).

Phenyltins

In general, little is known of the environmental fate and behaviour of the phenyltin compounds in the aquatic environment (Fig. 3). In surface waters to a depth of approximately 0.5 m, it is probable that photolysis will be the major degradation pathway for triphenyltin. The half-life for triphenyltin photolysis in water exposed to natural sunlight or in a photoreactor was reported to be 14–21 d; no triphenyltin degradation was observed in solutions kept in the dark for 30 d (Slesinger and Dressler 1978; Soderquist and Crosby 1980). Photolytic degradation appears to occur by way of sequential dearylation, and evidence exists for the formation of water-soluble polymeric di- and monophenyltin compounds. Once formed, the di- and monophenyltin compounds are rapidly hydrolyzed, with a half-life of 2–3 d. Volatilization of triphenyltin was not detected in a 6-d experiment, even at temperatures as high as 32°C, at which water loss was significant (Soderquist and Crosby 1980).

The major degradation pathway for triphenyltin in waters or sediments not directly exposed to light is likely to be aerobic biodegradation (Smith 1981b). The reported half-life is 60–140 d, with diphenyltin as the major degradation product. No studies were found that investigated triphenyltin degradation rates under anaerobic conditions.

Microbial degradation of triphenyltins in soil is usually rapid, although the actual rate is dependent on the type of soil and triphenyltin compound applied. Generally, complete degradation of triphenyltin acetates and hydroxides occurs within 12–240 h. Experiments monitoring $^{14}CO_2$ evolution from ^{14}C-labelled triphenyltin compounds did not find any evidence of degradation when sterilized soil was used (Barnes *et al.* 1973; Suess and Eben 1973). Laboratory experiments have also isolated a number of different kinds of bacteria and fungi capable of degrading triphenyltin to inorganic tin in soil (Bock 1981). Because triphenyltin is used primarily as a pest control product for agricultural crops and is rapidly biodegraded, its impact would probably be limited to nearby water sources only. Hence, few studies have investigated the fate and behaviour of phenyltin compounds in aquatic ecosystems, particularly in the marine environment (Fig. 3).

Other Organotins

NRCC (1985) summarized the available fate and behaviour information for organotins other than the methyltin, butyltin, and phenyltin groups of compounds. In general, little information was available. Mazayev *et al.* (1976) found that diethyltin had a half-life of 1.5 d in pond water and 2.5 d in a pond water/sediment mixture. The corresponding half-lives for dioctyltin were 6.2 and 1.9–4.7 d, respectively. The degradation reaction in both cases was described, without elaboration, as "hydrolysis," and the products of the reaction were not stated. Casida *et al.* (1971) and Smith *et al.* (1976) found that mono-, di-, and tricyclohexyltin underwent photolytic degradation in water (half-lives not stated) to cyclohexanone and cyclohexanol. The half-life of tricyclohexyltin was found to be <35 d in apples and pears (Getzendaner and Corbin 1972) and >3 years in the 0- to 15- cm soil layer (Blair 1975). The major products in both cases were di- and monocyclohexyltin and inorganic tin. No other information on the fate and behaviour of organotin compounds in the environment was found.

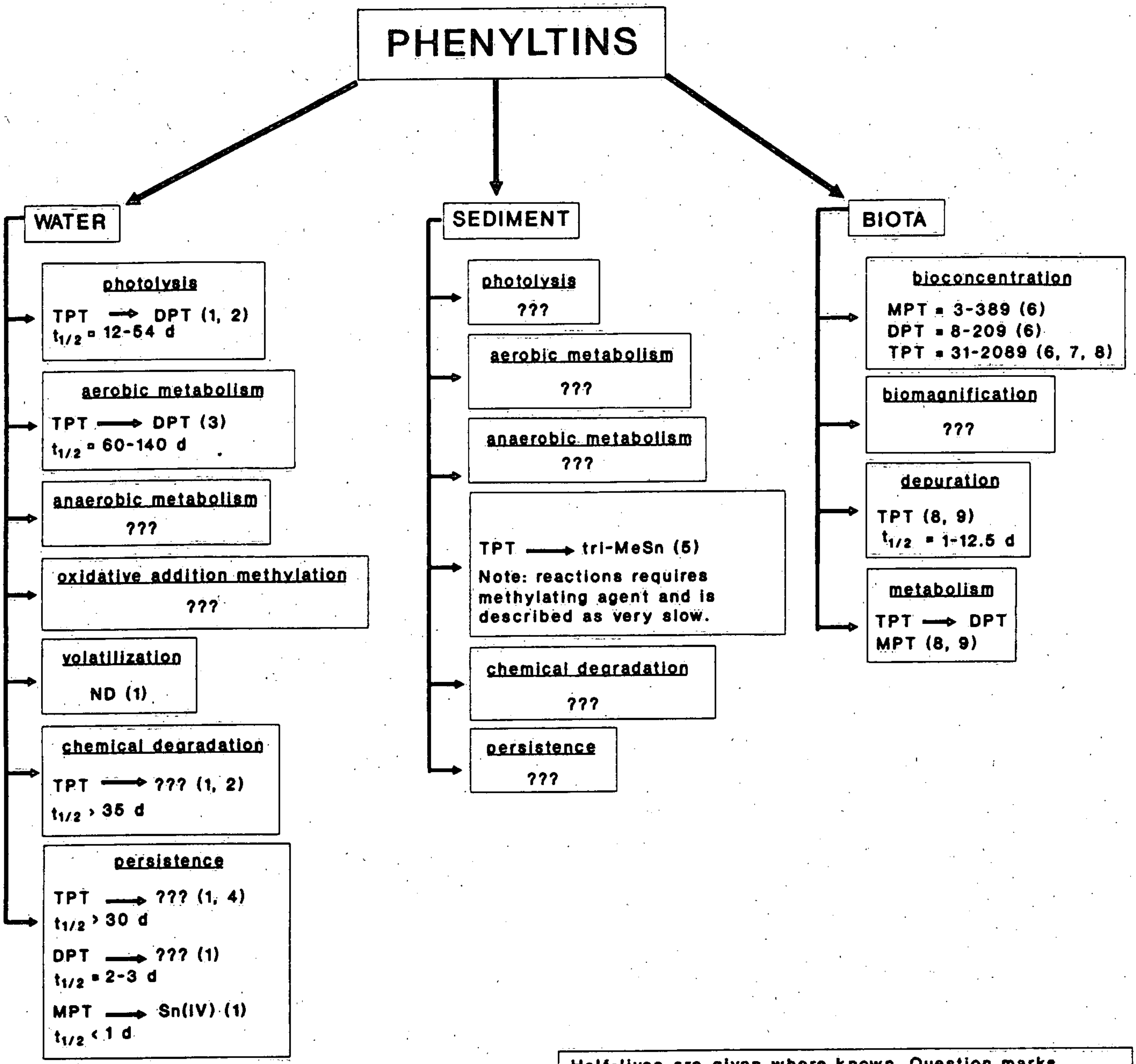
BIOACCUMULATION

Accumulation

General Observations

The potential for aquatic biota to bioconcentrate organotins from the environment is dependent upon the specific number and types of organic moieties attached to the tin atom. The greater the number and molecular weight of the organic groups bound to the tin atom, the more lipophilic the compound and the greater the potential for bioconcentration (NRCC 1985).

Most organotins have a moderately high octanol/water partition coefficient (e.g., bis(tributyltin) oxide



Half-lives are given where known. Question marks indicate that the process has not been studied, whereas ND indicaes that the process has been studied but was found not to occur at a detectable rate. References are: (1) Soderquist and Crosby 1980; (2) Slesinger and Dressler 1978; (3) Smith 1981 b; (4) Duncan 1980; (5) Chau *et al.* 1981; (6) Tsuda *et al.* 1987a; (7) Tsuda *et al.* 1986a; (8) Tsuda *et al.* 1987b; and (9) Tsuda *et al.* 1988.

•Medium = water/sediment mixture

Figure 3. Potential fate processes for the phenyltins.

K_{ow} = 200–7000) (Maguire *et al.* 1983; Tsuda *et al.* 1986a; Laughlin *et al.* 1986b), indicating that these compounds have the potential to bioaccumulate in aquatic biota. The K_{ow} for tributyltin varies as a function of salinity; a K_{ow} of 5500 occurs at a salinity of 25 $g{\bullet}L^{-1}$, and a K_{ow} of 6300 occurs at a salinity of 45 $g{\bullet}L^{-1}$. The K_{ow} of tributyltin in seawater is most stable at salinities between 15 and 32 $g{\bullet}L^{-1}$. A major decrease in the tributyltin K_{ow} occurs at salinities below 5 $g{\bullet}L^{-1}$ primarily because of a lack of ionic stabilization on the charged tributyltin species (Laughlin *et al.* 1986b).

Several other factors are thought to have affected the K_{ow} values reported in the literature. For example, breakdown products such as di- and mono-organotin species, which may be formed during synthesis or storage of the test material, enrich the aqueous phase of the octanol/water system, thus lowering the final K_{ow} value (Laughlin *et al.* 1986b). Order-of-magnitude changes in K_{ow} values have also been observed after changing the octanol/water ratio in the test solution (Tsuda *et al.* 1986a).

Filter-feeding invertebrates have bioconcentration factors that may exceed 10 000 on a wet-weight basis (Waldock and Thain 1983). Entry of tributyltins into bivalves is enhanced by their particular mode of feeding, which involves passing currents of water over gill membranes and collecting the particulate material from the water. Thus, organotins both dissolved in the water and adsorbed to particulate materials have the potential to be taken up by the gill apparatus or intestinal tract of the bivalve. Once taken up through the gills, the organotins are rapidly distributed to other tissues via the vascular system. Final tissue burdens are apparently influenced by tissue lipid content, such that tributyltin tissue concentrations range from highest to lowest in the following order: gill > viscera > mantle > adductor muscle (Laughlin and French 1988). Accumulation of tributyltin by bivalves from particulate material (e.g., phytoplankton) is more rapid than from water for an equivalent concentration of tributyltin (Laughlin *et al.* 1986a). The accumulated tributyltin from particulate material is also transported to various tissues, except that the viscera rather than the gills have the highest observed concentrations (Laughlin 1986).

An inducible clearance system has been hypothesized for bivalves, such that body burdens can be reduced to a steady-state or equilibrium condition at low concentrations (e.g., 45 $ng{\bullet}L^{-1}$ bis(tributyltin) oxide or less). However, at higher concentrations (e.g., 63 $ng{\bullet}L^{-1}$ bis(tributyltin)oxide or greater), the clearance system is overwhelmed, leading to a continued increase in tributyltin body burden over the duration of the exposure period (Laughlin and French 1988).

Bioaccumulation has been less studied in fish than in bivalves. Those studies that have been conducted found an inverse relationship between exposure concentration (dissolved in water) and the measured bioconcentration factor (Davies and McKie 1987; Tsuda *et al.* 1988). Internal distribution is a function of tissue type. The liver accumulates the highest concentration, followed by the viscera and then muscle in marine and estuarine fish (Laughlin 1986). Freshwater fish accumulate tributyltin dissolved in water to the highest levels in the peritoneal fat followed by the liver, gall bladder, kidney, and other tissues, including the muscle (Martin *et al.* 1989).

Reported accumulations of tributyltin in bacteria and phytoplankton of between 600 and 30 000 times the water concentration are thought to be the result of surface adsorption rather than assimilation (Cardwell and Sheldon 1986). However, there is evidence of tributyltin metabolism in algae (Maguire *et al.* 1984), thus indicating some absorption into the microbes.

Methyltins

There have been few studies to date that have measured methyltin bioconcentration factors in aquatic biota. Macroalgae in San Diego Bay have been found to have elevated methyltin concentrations; however, these organotin compounds may be of biogenic origin, resulting from the methylation of inorganic Sn(IV) by epiphytic bacteria (Seidel *et al.* 1980). Donard *et al.* (1987) found that the mono-, di-, tri-, and tetramethyltin compounds cycled as a result of methyl group redistribution reactions on macroalgal surfaces. It is difficult to experimentally discern how much of the methyltin burden in algae is a result of bioconcentration from the surrounding waters and how much is due to surface biosynthesis and redistribution. Several authors have cited a bioconcentration factor of approximately 1000, although experimental evidence is still lacking (Ring and Weber 1988).

Butyltins

Numerous studies have been conducted to document the bioaccumulation potential of butyltin compounds, particularly tributyltin, in aquatic biota (Appendix E). For marine fish species, tributyltin bioconcentration factors have been found to range from 200 in the muscle tissue of chinook salmon (*Oncorhynchus tshawytscha*) (Short and Thrower 1986a, 1986c) to 4580 in the viscera of sheepshead minnow (*Cyprinodon variegatus*) (Ward *et al.* 1981). Ward *et al.* (1981) found that sheepshead minnow exposed to 1.6 $\mu g{\bullet}L^{-1}$ tributyltin had whole-fish bioconcentration factors of 547 after 14 d, 1490 after 28 d, and 2600 after 58 d. Equilibrium between water concentration and concentration of tributyltin was not reached in this study. No studies are available for mono- and dibutyltin bioconcentration in marine fish species. The corresponding whole-fish bioconcentration factors for freshwater fish have been shown to range from 406 in rainbow trout (*Oncorhynchus mykiss*) after a 64-d exposure to 0.51 µg•L^{-1} tributyltin (Martin *et al.* 1989) to 1230 in goldfish, (*Carassius auratus*) after a 14-d exposure to 2.0 µg•L^{-1} tributyltin (Tsuda *et al.* 1988). In a study by Tsuda *et al.* (1986a), dibutyltin and monobutyltin were found to have bioconcentration factors 2–3 and 1–2 orders of magnitude less, respectively, than tributylin in the corresponding tissues (Appendix E).

Tributyltin bioconcentration factors in whole bodies of marine invertebrates have been found to range from a low of 192 in the oyster *Ostrea edulis* after a 45-d exposure to 2.62 µg•L^{-1} tributyltin from panels coated with antifouling paint (Thain and Waldock 1985; Thain 1986) to a high of 250 000 in the snail *Nucella lapillus* after a 540-d exposure to 0.001–0.002 µg•L^{-1} Sn in tributyltin (Gibbs *et al.* 1988). The different procedures used in these experiments probably explain much of the observed variation in results. No studies have been conducted to determine the bioconcentration potential of di- and monobutyltin in marine invertebrates. In the only butyltin bioconcentration study conducted on freshwater invertebrates, Holwerda and Herwig (1986) found that the clam *Anodonta anatina* had bioconcentration factors ranging from 9 in the mantle to 1570 in the kidney after a 210-d exposure to 38 µg•L^{-1} dibutyltin.

After a 14-d exposure to 0.067 µg•L^{-1} tributyltin, the marine vascular plant eelgrass (*Zostera marina*) was found to have a bioconcentration factor of 12 000 (François *et al.* 1989). No comparable studies are available for di- and monobutyltin bioaccumulation in marine plant and algal species or for any butyltin compound in freshwater plant and algal species (Appendix E).

Phenyltins

In general, the bioconcentration factors observed for phenyltin compounds in aquatic biota are lower than those observed for the corresponding butyltin compounds (Appendix E). In a 14-d test, Tsuda *et al.* (1988) found that freshwater goldfish (*Carassius auratus*) exposed had a whole-fish bioconcentration factor of 257. In a study that compared the bioconcentration potential of mono-, di-, and triphenyltin in tissues of freshwater carp (*Cyprinus carpio*), Tsuda *et al.* (1987b) found that mono- and diphenyltin usually had similar bioconcentration factors for a particular tissue (e.g., 3.3 and 7.9, respectively, in muscle), whereas triphenyltin bioconcentration factors in the corresponding tissue were much higher (e.g., 269 in muscle). No other studies were available for marine or freshwater fish, invertebrates, or plants.

Other Organotins

No studies were found on the bioconcentration of other organotin compounds in marine or freshwater fish, invertebrates, or plants.

Metabolism and Elimination

The metabolism of organotin compounds by aquatic biota is generally thought to involve dearylation or dealkylation of the various organic moieties, producing the di- and mono- derivatives from the triaryl or trialkyl organotins. *In vivo* and *in vitro* studies of bis(tributyltin) oxide metabolism by blue crabs (*Callinectes sapidus*), spider crabs (*Libinia emarginata*), oysters (*Crassostrea virginica*), and the spot fish (*Leiostomus xanthurus*), using ^{14}C-labelled bis(tributyltin) oxide, demonstrated the formation of metabolites by the cytochrome P_{450}-dependent mixed-function oxygenase system (Lee 1985, 1986). Exposure of the crabs and fish to ^{14}C-labelled bis(tributyltin) oxide resulted in the gradual accumulation of radioactivity in the hepatic tissues. After 48 h in the *in vitro* studies, 40%–50% of the radioactivity was associated with bis(tributyltin) oxide metabolites, including hydroxylated dibutyl- and monobutyltin compounds. Conversely, oysters metabolized the bis(tributyltin) oxide at a much slower rate. After 72 h, dibutyltin and polar metabolites accounted for only about 10% of the radioactivity in the digestive gland (Lee 1985, 1986).

Studies on the excretion patterns of organotins by aquatic biota generally indicate an initial period of rapid excretion after exposure ceases, followed by a secondary period of much slower excretion. This pattern is shown with triphenyltin elimination from goldfish (*Carassius auratus*) (Tsuda *et al.* 1988). The rate of elimination for the first 20% of the triphenyltin burden corresponded to a half-life of 6 d, whereas the remainder had a calculated half-life of 1.3 years. Short-term (3 d) studies of tributyltin and triphenyltin excretion by carp (*Cyprinus carpio*) demonstrated elimination from the muscle tissue but not from the liver, kidney, or gallbladder (Tsuda *et al.* 1987a). These results probably represent the translocation of organotins from muscle tissue to the liver, kidney, and gallbladder. Longer (64 d) metabolism and depuration studies with rainbow trout (*Oncorhynchus mykiss*) demonstrated elevated levels of tributyltin metabolites in the liver and gallbladder. This suggested that tributyltin was dealkylated in the liver and excreted in the bile. Similar processes are known to occur in mammals (Martin *et al.* 1989).

The fact that relatively high concentrations of tributyltin have been noted in fish kidneys is not an indication that this organ plays a major role in the excretion of tributyltin and its metabolites. A more probable explanation is that the kidney levels are the result of tributyltin and metabolite translocation from the liver via the blood, and that the kidney tissue has an affinity for ionized electrolytes (Martin *et al.* 1989).

TOXICITY TO BIOTA

Toxicity to Aquatic Biota

Because standard protocols for toxicity testing may become outdated or are not always available or followed, a great deal of variability exists in the quality of published toxicity data. To ensure a consistent scientific evaluation for each organotin compound, the data used in deriving a guideline must meet certain criteria as outlined in CCREM (1987a). These criteria include information on test conditions/design (e.g., flow-through, static), test concentrations, temperature, water hardness, pH, experimental design (e.g., controls, number of replicates), and a description of the statistics used in evaluating the data. Each study is evaluated based on the above information and ranked as primary, secondary, or unacceptable (see CCREM 1987a for a detailed description of the ranking criteria). Further, to ensure that each guideline is protective of all forms of aquatic life, it is necessary to include data from fish, invertebrates, and plants to complete a minimum data set for each organotin compound (CCREM 1987a). All data included in the minimum data set must be primary for full guideline derivation to proceed; however, if a more sensitive value is found in a secondary study, this may be used to generate the guideline if the minimum data set is met. For interim guideline derivation, primary or secondary data may be used. Toxicity data that do not meet the criteria of primary or secondary data are unacceptable and cannot be used in either derivation procedure.

The toxicological data base for organotins is quite large, particularly for tributyltin (Appendices F, G, and H). However, many of the available studies were ranked as unacceptable and will not be considered further in this report. The most common reasons for an unacceptable ranking were that the biological responses (e.g., survival) of the control treatment were not provided, or that the information was from a secondary source and the original study could not be retrieved. The following section describes major trends in the toxicological data base for organotins. Subsequent sections describe the toxicological data base for specific organotins, with particular emphasis on the studies necessary to complete the minimum data set requirements for each compound. All reported concentrations in primary and secondary studies have been converted, where necessary, to micrograms of the organotin cation per litre.

General Observations

A large portion of the toxicity data generated prior to the 1970s was directed toward gastropods and the control of schistosomiasis (e.g., Frick and de Jimenez 1964; Deschiens *et al.* 1966; Hopf *et al.* 1967). Continued interest in the biocidal applications of organotins has prompted additional testing with other organisms and more sensitive life stages. This is especially true for tributyltin because of concerns about its use in antifouling paints and the associated effects on estuarine shellfish productivity. Figure 4 indicates that marine invertebrates, particularly the bivalve species, are the most sensitive types of aquatic organisms to acute tributyltin toxicity. Other groups of aquatic biota appear to be less sensitive, although there are order-of-magnitude differences in sensitivity among species in any one group.

The toxicity of organotin compounds is dependent upon the structure of the side chain and correlates well with the hydrophobic behaviour of the specific compounds. The mode of action appears to be related to the destabilization of the pH gradient across membranes and the physical disruption of membranes following excessive organotin accumulation (Selwyn *et al.* 1970; Laughlin *et al.* 1985a; Gray *et al.* 1986). Figure 5 indicates that triorganotin compounds appear to be more toxic than di- or monoorganotins. As well, alkyltin toxicity appears to be correlated with side-chain length (i.e., butyl > propyl > ethyl > methyl) (Fig. 5). The only aryltins for which acceptable toxicity information exists are the phenyltin compounds, which appear to be as toxic as the butyltin compounds (Fig. 5). The anionic radical associated with the butyltin cation (e.g., chloride, fluoride, hydroxide, oxide, acetate) has been shown to have little influence on the aquatic toxicity of the organotin compound of interest (Linden *et al.* 1979; Walsh *et al.* 1985).

Toxicity studies with the oyster *Crassostrea virginica* indicated that tributyltin-induced mortality was greater at higher seawater salinity levels (Bokman and Laughlin 1989). Other environmental factors can also alter the toxic effects of organotins on aquatic biota. For example, the binding of tributyltin to microorganism-produced extracellular products or invertebrate polyionic slimes may be significant in reducing organotin toxicity (Laughlin 1986). This is apparently the reason for tributyltin tolerance in several marine algal species (Thomas and Robinson 1987).

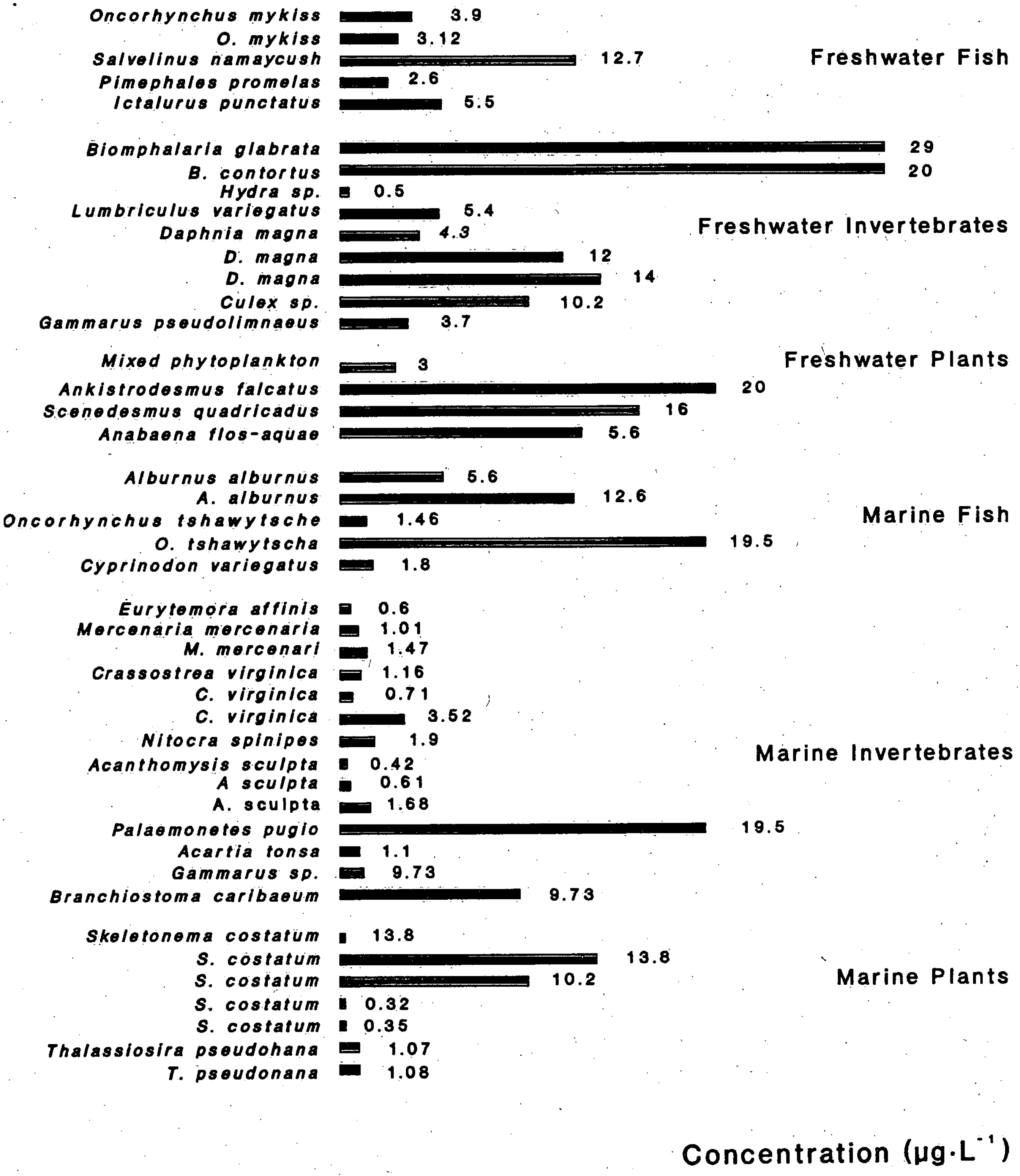


Figure 4. Observed significant responses in marine and freshwater biota after acute exposures to tributyltin.

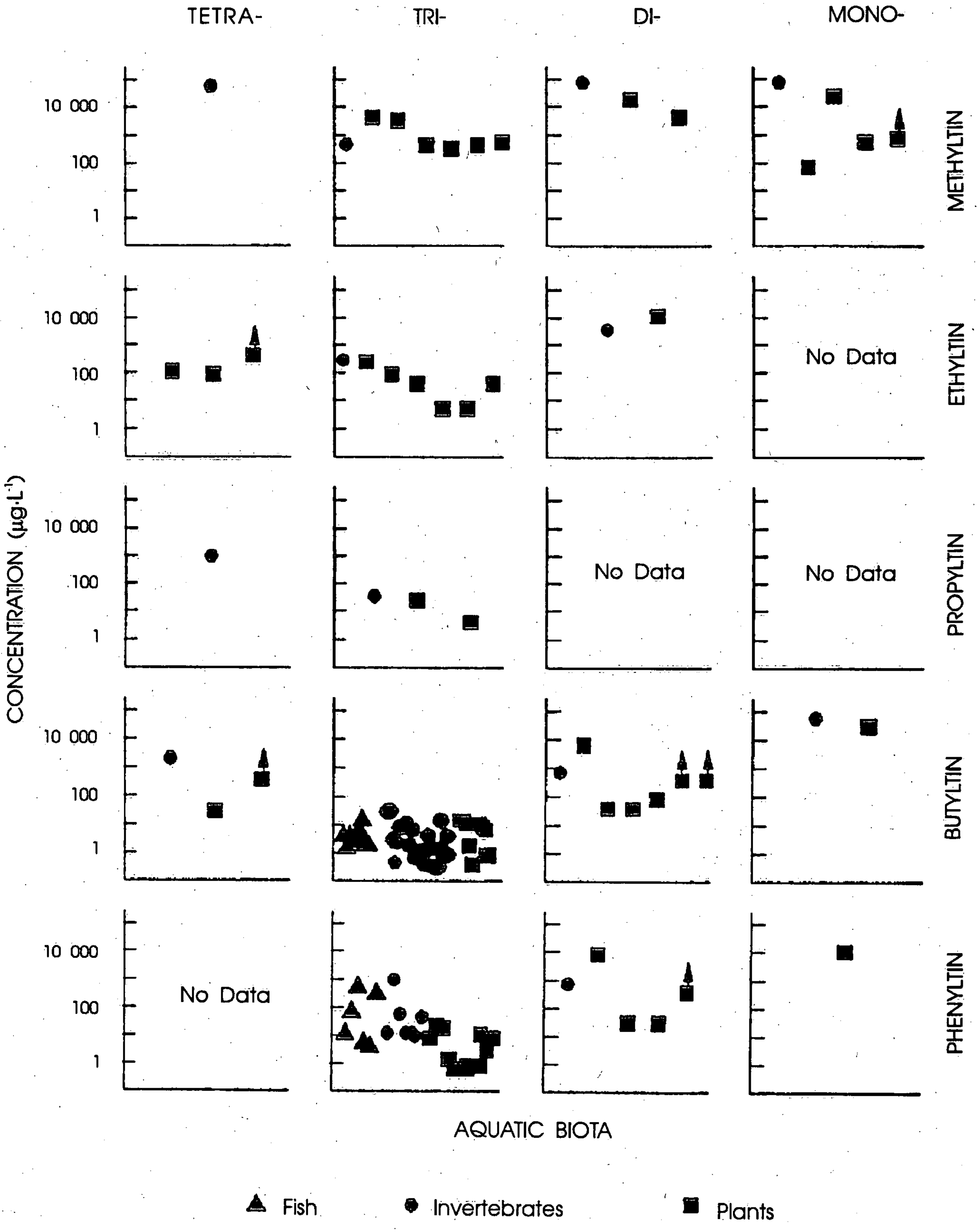


Figure 5. Observed significant responses in marine and freshwater biota after acute exposures to mono-, di-, tri-, and tetraorganotins.

Commercial production of the oyster *Crassostrea gigas* has been shown to have been severely affected by the presence of tributyltin in Arcachon Bay, France, prior to a 1982 ban (Alzieu 1986; Alzieu *et al.* 1986). The larvae produced in the presence of sublethal concentrations of organotin compounds were weak and unable to attach to collectors. Those that did attach developed shell deformities as a result of organotin interference with the shell calcification process (Alzieu *et al.* 1980, 1982). Another sublethal effect that has been extensively documented in gastropods in both field and laboratory studies is the superimposition of male sex characteristics in females. The widespread incidence of imposex (male genitalia imposed on females) has caused a decline in populations of dog-whelk (*Nucella lapillus*) and other neogastropod mulluscs (Smith 1981a, 1981b; Bryan *et al.* 1986, 1987, 1988; Gibbs and Bryan 1986, 1987; Davies *et al.* 1987; Gibbs *et al.* 1987; Bailey and Davies 1988a, 1988b; Ellis and Pattisina 1990; Saavedra Alvarez and Ellis 1990).

Observations of renal tissue pathology have shown extensive hydropic degeneration of the tubular epithelial cells in rainbow trout (*Oncorhynchus mykiss*) exposed to a lethal level of 5 $\mu g \bullet L^{-1}$ tributyltin chloride for 10 d (Seinen *et al.* 1981). The same species exposed to 0.2 $\mu g \bullet L^{-1}$ tributyltin chloride for 110 d exhibited enlarged liver and hepatocyte hyperplasia with abnormal nuclear morphology accompanied by swollen and vacuolated cytoplasm (Seinen *et al.* 1981). Pathological alterations of gill epithelium have also been reported after 6-d exposures to 11.7 $\mu g \bullet L^{-1}$ bis(tributyltin) oxide (Chliamovitch and Kuhn 1977). These alterations apparently did not occur after a 110-d exposure to 5 $\mu g \bullet L^{-1}$ tributyltin chloride (Seinen *et al.* 1981). Corneal damage was observed after a 24-h exposure to 5 $\mu g \bullet L^{-1}$ bis(tributyltin) oxide for the Mozambique mouthbrooder (*Tilapia mossambica*), a tropical freshwater fish (Matthiessen 1974). The histopathological effects of chronic, sublethal exposure to bis(tributyltin) oxide in the guppy (*Poecilia reticulata*) were found to be thymus atrophy, liver vacuolation, and hyperplasia of the hematopoietic tissues (Wester and Canton 1987).

Organotins as a group are significant inhibitors of enzyme activity, including the Mg-, Na-, and K-ATPases (adenosine triphosphatases). *In vitro* experiments have demonstrated 50% inhibition of fish brain Mg-ATPase at 0.025 $\mu g \bullet L^{-1}$ tricyclohexyltin hydroxide (Plictran). Fifty percent inhibition of the Na- and K-ATPases occurred with 77 $\mu g \bullet L^{-1}$ Plictran in the same experiment (Desaiah *et al.* 1973). Digestive enzymes as well as alkaline phosphatase and alanine amino transferase were also substantially affected by exposure of fish to trimethyltin chloride concentrations as low as 10 $\mu g \bullet L^{-1}$. However, stabilization of the biochemical effects induced by organotin exposure to trimethyltins indicated some adaptation by the fish to these concentrations (Putintsev and Gameza 1980). Exposure of rainbow trout (*Oncorhynchus mykiss*) to 1 $\mu g \bullet L^{-1}$ tributyltin chloride for 110 d significantly decreased the number of red blood cells. This effect was not observed at 0.2 $\mu g \bullet L^{-1}$ (Seinen *et al.* 1981).

Organotin uptake via the gills lowered the effectiveness of phosphorus incorporation by the carp (*Cyprinus carpio*) (Filenko and Parina 1981, 1983). As well, a 40-d exposure to 10 $\mu g \bullet L^{-1}$ triethyltin chloride changed the uptake and distribution of carbon, which were reflected by changes in carbohydrate, fat, and protein metabolism in the brain, liver, and muscles (Stroganov *et al.* 1974). Carbohydrate metabolism was severely affected by long-term exposure of fish to low concentrations of trialkyltins resulting in the depletion of liver glycogen.

Methyltins

Figure 5 indicates that the methyltin compounds are the least toxic to aquatic biota of the methyl-, ethyl-, propyl-, and butyltin series of compounds. However, because these compounds can be produced by natural processes from inorganic tin, methyltins are of environmental concern in areas where tin loadings are significant as a result of tributyltin degradation (e.g., marinas) or where there is a natural abundance of inorganic tin in the earth's crust.

Few studies have been conducted to test the effects of methyltin compounds on freshwater aquatic biota (Tables F-1, G-1, and H-1). In acute exposure tests on *Daphnia magna*, Vighi and Calamari (1985) determined 24-h IC_{50} values of 50, 65, 0.39, and 40 $mg \bullet L^{-1}$ for mono-, di-, tri-, and tetramethyltin, respectively. Wong *et al.* (1982) conducted 4-h acute exposure tests on three species of freshwater algae to determine the methyltin concentrations that caused a 50% reduction in $^{14}C\text{-}HCO_3$ uptake (IC_{50}). For the green alga *Ankistrodesmus falcatus*, 4-h IC_{50} values of 23, 21, and 5.5 $mg \bullet L^{-1}$ were determined for mono-, di-, and trimethyltin, respectively. For the green alga *Scenedesmus quadricauda*, 4-h IC_{50} values of 4.1 and 2.6 $mg \bullet L^{-1}$ were determined for di- and trimethyltin, respectively. The blue-green alga *Anabaena flos-aquae* was found to be a relatively tolerant species, with a 4-h IC_{50} value of >5000 $mg \bullet L^{-1}$ for both di- and trimethyltin. The most sensitive response demonstrated for phytoplankton was observed when an assemblage of phytoplankton species indigenous to Lake Ontario was exposed to trimethyltin. The resulting IC_{50} was

0.35 mg•L^{-1}. All of the above studies were ranked as secondary because methyltin concentrations were not measured during the course of the tests. No acceptable methyltin toxicity data were found for freshwater fish.

For marine aquatic species, acceptable toxicity data were available for one invertebrate and two diatom species (Tables G-2 and H-2). Studies on the mud crab (*Rhithropanopeus harrisii*) reported 14-d LC$_{50}$s of 92 µg•L^{-1} for trimethyltin hydroxide and 13.7 mg•L^{-1} for dimethyltin dichloride (Laughlin *et al.* 1984a, 1985b; Laughlin 1987). For the diatom *Skeletonema costatum*, 72-h EC$_{50}$ values for population growth ranged from 42.6–43.7 µg•L^{-1} for the monomethyltin cation to 173–176 µg•L^{-1} for trimethyltin. The 72-h LC$_{50}$ values for mono- and dimethyltin for this species were both above 250 µg•L^{-1} (death of individual cells was determined by staining) (Walsh *et al.* 1985, 1987; Walsh 1986). Another diatom species, *Thalassiosira pseudonana*, had EC$_{50}$ values for population growth of 190–192 and 284–287 µg•L^{-1} for mono- and trimethyltin, respectively (Walsh *et al.* 1985). The above studies were given a secondary ranking because methyltin concentrations were not determined during the course of the tests.

Butyltins

There is an extensive freshwater aquatic life toxicity data base for the butyltin compounds, particularly tributyltin (Tables F-1, G-1, and H-1). For freshwater fish, there are seven studies ranked as primary available for tributyltin. Acute 96-h exposure studies indicated similar responses among cold- and warm-water species. The cold-water species, *Oncorhynchus mykiss* and *Salvelinus namaycush*, had 96-h LC$_{50}$ values of 3.12–3.9 µg•L^{-1} (Brooke *et al.* 1986; Martin *et al.* 1989) and 12.7 µg•L^{-1} (Martin *et al.* 1989), respectively, whereas the warm-water species, *Pimephales promelas* and *Ictalurus punctatus*, had 96-h LC$_{50}$ values of 2.6 and 5.5 µg•L^{-1} (Brooke *et al.* 1986), respectively. Chronic tributyltin toxicity tests have been conducted for post-hatch fathead minnows (*P. promelas*) and the guppy (*Poecilia reticulata*) under flow-through conditions. The 33-d lowest-observed-effect level (LOEL) (for reduction in mean standard length) in fathead minnows was 0.08 µg•L^{-1} (Brooke *et al.* 1986), whereas the 90-d LOEL for histopathological changes (hyperplasia of the hematopoietic tissue) in the guppy was 0.031 µg•L^{-1} (Wester and Canton 1987). In comparison, Wester and Canton (1987) found that the dibutyltin cation was much less toxic to guppies, with a 30-d LOEL for histopathological changes (thymus atrophy, liver vacuolation, and hyperplasia of hematopoietic tissue) of 245 µg•L^{-1}. No other primary or secondary studies were available for either di- or monobutyltin.

In general, freshwater invertebrates had similar responses to acute and chronic exposures to tributyltin as did fish. In tributyltin tests ranked as primary, Brooke *et al.* (1986) found that *Hydra* sp. had a 96-h EC$_{50}$ (shortened body column or tentacles) of 0.5 µg•L^{-1}, *Daphnia magna* had a 48-h EC$_{50}$ (complete immobilization) of 4.3 µg•L^{-1}, *Gammarus pseudolimnaeus* had a 96-h LC$_{50}$ of 3.7 µg•L^{-1}, *Lumbriculus variegatus* had a 96-h EC$_{50}$ (delayed response to prodding) of 5.4 µg•L^{-1}, and *Culex* sp. had a 96-h EC$_{50}$ (complete immobilization) of 10.2 µg•L^{-1}. In the only available chronic tributyltin exposure test, *Daphnia magna* exhibited a significant reduction in the number of young produced per adult surviving a 21-d exposure and in the number of young produced per adult per reproductive day at a concentration of 0.2 µg•L^{-1} (Brooke *et al.* 1986). In a study on the snail *Biomphalaria glabrata*, Ritchie *et al.* (1974) found significantly reduced egg laying after exposure to 0.001 µg•L^{-1} bis(tributyltin) oxide for 85 d after hatching. This study was deemed unacceptable because the test was conducted under static renewal conditions over 85 d as opposed to flow-through conditions, and because other experimental conditions were not sufficiently reported. For di- and monobutyltin, only one study ranked as secondary was available for freshwater invertebrates. The test was conducted on young (<24 h old) *Daphnia magna* under static test conditions with unmeasured concentrations and resulted in 24-h IC$_{50}$ values of 690 and 30 400 µg•L^{-1} for di- and monobutyltin, respectively (Vighi and Calamari 1985).

No studies ranked as primary were available for freshwater plant species exposed to mono-, di-, or tributyltin (Table H-1). In static tests with unmeasured butyltin concentrations, Wong *et al.* (1982) determined the nominal concentrations causing a 50% reduction in primary productivity, as measured by ^{14}C-HCO$_3$ uptake (IC$_{50}$), in single and mixed phytoplankton species tests. For the green alga *Ankistrodesmus falcatus*, the 4-h IC$_{50}$ values for mono-, di-, and tributyltin were 25, 6.8, and 0.02 mg•L^{-1}, respectively. The 4-h IC$_{50}$ values for the green alga *Scenedesmus quadricauda* and the blue-green alga *Anabaena flos-aquae* were 0.016 and 0.013 mg•L^{-1} tributyltin, respectively. The most sensitive phytoplankton response was demonstrated when a mixed phytoplankton assemblage from Lake Ontario was tested; the 4-h IC$_{50}$ value was 0.003 mg•L^{-1} tributyltin. In other longer-term studies of tributyltin effects on freshwater phytoplankton, 14-d complete inhibition of growth responses was demonstrated at concentrations ranging from 0.056 mg•L^{-1} for the golden alga *Raphidonema longiseta* to 1.78 mg•L^{-1} for the yellow-green alga *Monodus subterraneous* (Blanck *et al.* 1984; Blanck 1986).

Primary studies conducted under flow-through conditions and with measured tributyltin concentrations are available for three marine fish species (Table F-2). In the first study, Pinkney *et al.* (1985) determined the tributyltin levels that elicited avoidance behaviour in mummichog (*Fundulus heteroclitus*) during a 40-min exposure. The significant LOEL for this test was 3.7 μg Sn•L^{-1}; however, at 1.0 μg•L^{-1}, four out of six replicate fish groups also exhibited avoidance behaviour, although the authors did not find this to be significant. Thus, 1.0 μg•L^{-1} cannot be considered as a no-observed-effect level (NOEL) value (no lower concentrations were tested). Chronic tributyltin toxicity tests were conducted with juvenile Atlantic menhaden (*Brevoortia tyrannus*) and larval inland silverside (*Menidia beryllina*) (Hall *et al.* 1988c). Twenty-eight-day exposures to tributyltin concentrations of 0.093 and 0.49 μg•L^{-1} did not significantly affect the survival of either species or cause any significant histological changes. However, significant reductions in growth were noted for *M. beryllina* at both tributyltin test concentrations. No acceptable toxicity studies for either di- or monobutyltin are available for marine fish species.

The tributyltin toxicity data base is extensive for marine invertebrates and includes 14 studies ranked as primary (Table G-2). Acute tests indicated varied sensitivity to tributyltin exposure for five species of marine invertebrates, with 96-h LC$_{50}$ values ranging from 0.42 μg•L^{-1} for juvenile mysid shrimp (*Acanthomysis sculpta*) (Davidson *et al.* 1986a, 1986b) to 19.5 μg•L^{-1} for grass shrimp (*Palaemonetes pugio*) (Clark *et al.* 1987). Chronic exposure tests have also indicated a narrow range of sensitivity to tributyltin among the five species of marine invertebrates tested thus far. Responses reported in primary studies ranged from a 6-d LOEL (reduction in survival) of 0.023–0.024 μg•L^{-1} for nauplii of the copepod *Acartia tonsa* (Bushong *et al.* 1990) to a 66-d LC$_{50}$ of 0.97 μg•L^{-1} for the bay mussel (*Mytilus edulis*) (Valkirs *et al.* 1987a). However, several secondary studies found significant effects at lower concentrations. Spat of the oyster *Crassostrea gigas* showed significantly reduced ability to compensate for hypoxia at a concentration of 0.01 μg•L^{-1} (Lawler and Aldrich 1987), and dog-whelk (*Nucella lapillus*) exhibited a high percentage of imposex at 0.019 μg•L^{-1} (Bryan *et al.* 1986). Laughlin *et al.* (1988) found that 0.01 μg•L^{-1} bis(tributyltin) oxide inhibited growth in the clam *Mercenaria mercenaria*. Acceptable studies for dibutyltin dichloride were found for only one marine invertebrate species, mud crab (*Rhithropanopeus harrisii*) zoeae, with a 14-d LC$_{50}$ of 661 μg•L^{-1} (Laughlin *et al.* 1984a, 1985b; Laughlin 1987). No toxicity studies on marine invertebrates of either primary or secondary rank were available for monobutyltin.

In the only marine plant study ranked as primary, Beaumont and Newman (1986) determined that the microalgal species *Pavlova lutheri, Dunaliella tertiolecta,* and *Skeletonema costatum* all had significant reductions in growth at 0.1 μg•L^{-1} tributyltin (no lower concentrations were tested). In acute tributyltin exposure tests ranked as secondary, responses ranged from a 72-h EC$_{50}$ (reduction in growth) of 0.30–0.37 μg•L^{-1} for the diatom *S. costatum* (Walsh *et al.* 1985, 1987; Walsh 1986) to a 30-min LOEL (reduction in uptake of nitrate, phosphate, and silicate) of 29.0 μg•L^{-1} (Thomas and Robinson 1987). Responses to acute exposures to dibutyltin ranged from a 72-h EC$_{50}$ of 23–53 μg•L^{-1} in *S. costatum* (Walsh *et al.* 1985, 1987; Walsh 1986) to a 72-h LC$_{50}$ of >300 μg•L^{-1} for the same species (Walsh *et al.* 1985). Similarly, acute tetrabutyltin exposures led to responses ranging from a 72-h EC$_{50}$ of 17.2–17.4 μg•L^{-1} for *S. costatum* (Walsh *et al.* 1985, 1987; Walsh 1986) to a 72-h LC$_{50}$ of >500 μg•L^{-1} for the same species (Walsh *et al.* 1985). No toxicity studies of either primary or secondary rank were available for monobutyltin for marine plant species.

Phenyltins

In the only study ranked as primary for freshwater fish, Jarvinen *et al.* (1988) determined the responses of larval fathead minnows (*Pimephales promelas*) to both acute and chronic exposures of triphenyltin. The results indicated a 96-h EC$_{50}$ (changes in behaviour) of 3.5 μg•L^{-1} and a 96-h LC$_{50}$ of 6.8 μg•L^{-1}. Brief exposures for 24 and 72 h demonstrated 96-h LC$_{50}$ values of 19.1 and 5.7 μg•L^{-1}, respectively, and 30-d LC$_{50}$ values ranged from 3.7 to 15.6 μg•L^{-1}. A continuous-exposure, 30-d chronic effect concentration, based upon reduced growth, was found to be 0.22 μg•L^{-1}. In other acute triphenyltin tests given a secondary ranking (Table F-1), responses ranged from a 96-h LC$_{50}$ of 14 μg•L^{-1} in rainbow trout (*Oncorhynchus mykiss*) (Tooby *et al.* 1975) to a 24-h LC$_{100}$ of 860 μg•L^{-1} for the eel *Anguilla anguilla* (Gras and Rioux 1965). No primary or secondary toxicity tests were available for di- and monophenyltin for freshwater fish.

Of the five freshwater invertebrate species that have been tested to determine responses to acute triphenyltin exposures (all studies were ranked as secondary), the cladocerans *Daphnia magna, D. pulex,* and *Ceriodaphnia dubia* (all <24 h old) were found to be the most sensitive, with 48-h EC$_{50}$ (immobilization) values of 13.8, 15.7, and 10.8 μg•L^{-1}, respectively (Kline *et al.* 1989). The other two invertebrate species tested, midge (*Chironomus riparius*) larvae and the isopod *Asellus aquaticus*, had 48-h LC$_{50}$ values of 30 and 660 μg•L^{-1}, respectively (Cotta-Ramusino and

Doci 1987). The only toxicity study available for diphenyltin indicated that *D. magna* (<24 h) was less sensitive to this compound than to triphenyltin; the 24-h IC_{50} was 520 µg•L^{-1} (Vighi and Calamari 1985). No toxicity data for freshwater invertebrates were available for monophenyltin.

In a study ranked as secondary, Wong *et al.* (1982) determined 4-h IC_{50} (the concentration causing a 50% reduction in $^{14}C\text{-}HCO_3$ uptake) values of 10 µg•L^{-1} for the green alga *Ankistrodesmus falcatus*; 40 µg•L^{-1} for the green alga *Scenedesmus quadricauda*; 20 µg•L^{-1} for the blue-green alga *Anabaena flos-aquae*; and 2 µg•L^{-1} for a mixed phytoplankton assemblage from Lake Ontario during exposure to triphenyltin. The corresponding 4-h IC_{50} values for *A. falcatus* for di- and monophenyltin were 8000 and 19 000 µg•L^{-1}, respectively. No other toxicity information was available for the phenyltin compounds for freshwater plants.

There is little available toxicity information on the effects of phenyltin compounds on marine biota (Tables F-2, G-2, and H-2). In the only toxicity test available for a marine fish species, Linden *et al.* (1979) determined a 96-h LC_{50} of 320–440 µg•L^{-1} for the bleak (*Alburnus alburnus*) in a triphenyltin exposure study ranked as secondary. For marine invertebrates, the only primary study found reported that the grass shrimp (*Palaemonetes pugio*) had a 96-h LC_{50} of 48.9 µg•L^{-1} triphenyltin (Clark *et al.* 1987). The mud crab (*Rhithropanopeus harrisii*) experienced 14-d LC_{50}s of 34 and 701 µg•L^{-1} for tri- and diphenyltin, respectively, in studies ranked as secondary (Laughlin *et al.* 1984a, 1985b; Laughlin 1987). No toxicity information on diphenyltin was available for marine fish species, nor on monophenyltin for marine fish and invertebrate species. For the marine diatom *Skeletonema costatum*, Walsh *et al.* (1985, 1987) and Walsh (1986) determined 72-h EC_{50} (decrease in growth) values of 0.63–0.84 and 20–25 µg•L^{-1} for tri- and diphenyltin, respectively. The corresponding LC_{50} values were 4.2–14.4 µg•L^{-1} triphenyltin and >400 µg•L^{-1} diphenyltin. For the marine diatom *Thalassiosira pseudonana*, 72-h EC_{50} values of 1.0–1.3 µg•L^{-1} and 29 µg•L^{-1} were determined for tri- and diphenyltin, respectively. No toxicity data for marine plant species were available for monophenyltin.

Other Organotins

Much of the toxicity research conducted on other organotin compounds was conducted during the 1960s (e.g., Frick and de Jimenez 1964; Ritchie *et al.* 1964; Seiffer and Schoof 1967; Hopf *et al.* 1967) and does not meet recently developed standards for toxicity testing as outlined in CCREM (1987a). For freshwater biota, only two secondary-ranked studies were available for organotin compounds not included in the methyltin, butyltin, or phenyltin groups of compounds. For young (<24 h) *Daphnia magna*, 24-h IC_{50} values were determined for diethyltin (2800 µg•L^{-1}), triethyltin (190 µg•L^{-1}), tripropyltin (32 µg•L^{-1}), and tetrapropyltin (1180 µg•L^{-1}) (Vighi and Calamari 1985). For the freshwater alga *Ankistrodesmus falcatus*, 4-h IC_{50} (50% decrease in $^{14}C\text{-}HCO_3$ uptake) values were available for diethyltin (16 000 µg•L^{-1}), triethyltin (200 µg•L^{-1}), and tripropyltin (20 µg•L^{-1}) (Wong *et al.* 1982). The 4-h IC_{50} value for triethyltin for the green alga *Scenedesmus quadricauda* was 100 µg•L^{-1}; for a mixed phytoplankton assemblage from Lake Ontario, the 4-h IC_{50} values for triethyltin and tripropyltin were 55 and 4 µg•L^{-1}, respectively (Wong *et al.* 1982). The above data indicate that the triorganotin compounds are the most toxic to freshwater biota and that the longer-side-chain propyltin compounds are more toxic than the ethyltin compounds (see Fig. 5).

Invertebrate toxicity data were available for only one species, the mud crab (*Rhithropanopeus harrisii*), from only one study, ranked as secondary. In 14-d exposures, LC_{50}s of 80.7 µg•L^{-1} triethyltin, 92.4 µg•L^{-1} tripropyltin, 90 µg•L^{-1} triisopropyltin, 26 µg•L^{-1} triisobutyltin, 7.2 µg•L^{-1} tricyclohexyltin, 2.58 mg•L^{-1} diethyltin, 2.86 mg•L^{-1} dipropyltin, 100 µg•L^{-1} dicyclohexyltin, and 7.47 mg•L^{-1} dibenzyltin were determined (Laughlin *et al.* 1984a, 1985b; Laughlin 1987). No toxicity information was available for marine fish species for any of the ethyltin, propyltin, cyclohexyltin, or other organotin compounds not previously discussed. Walsh *et al.* (1985, 1987) and Walsh (1986) conducted a series of toxicity tests (ranked as secondary) on marine phytoplankton species (Table H-2). For the diatom *Skeletonema costatum*, 72-h EC_{50} (50% decrease in population growth) values of 3.2 and 142–148 µg•L^{-1} were determined for tri- and tetraethyltin, respectively. The corresponding 72-h LC_{50} values for this species were 29 and >500 µg•L^{-1}. Another marine diatom species, *Thalassiosira pseudonana*, had 72-h EC_{50} values of 2.7–2.8 and 116–121 µg•L^{-1} for tri- and tetraethyltin, respectively. Based on the above limited data base, it appears that marine phytoplankton may be more sensitive to the acute toxic effects of ethyltin exposure than are freshwater phytoplankton.

Toxicity to Livestock and Related Biota

The number and composition of the organic moieties bonded to the tin atom determine the toxicity of organotin compounds to livestock and related biota (Appendices I–M).

Organotin toxicity to mammals generally decreases from tri- to monoorganotins. Tetraorganotins resemble triorganotins in their toxicity, but their effects are often less and somewhat delayed by comparison. Mammalian toxicity within each class of organotin compounds is determined by the number of carbon atoms per side chain. The lower homologues of the trialkyltin series, trimethyl- and triethyltin, are the most toxic. Increases in the n-alkyl chain length reduce mammalian toxicity to the extent that trioctyltin compounds are essentially non-toxic (Snoeij *et al.* 1987a). Although it is generally regarded that the anionic radical of the organotin compound has little effect on biological activity, this does not seem to be the case if the anionic group becomes involved in the formation of a polymeric structure or a chelated monomer. In these cases, there is a reduction in the biological activity of the compound (Blunden *et al.* 1984).

Toxicity

A summary of the acute oral (i.e., single dose) toxicity of several tributyltin compounds is presented in Appendix I according to the specific anion. The rat LD_{50} values based on the total compound (i.e., tributyltin + anion) ranged from 94 to 224 $mg \cdot kg^{-1}$ body weight. However, when based on millimoles of tributyltin without consideration of the anion, the range was from 0.24 to 0.49 $mmol \cdot kg^{-1}$ body weight. Thus, the anions in these particular cases had little to do with the toxicity of the tributyltin compounds. A summary of repeated-dose oral toxicity studies is presented in Appendix J. Physicochemical investigations support the conclusion that regardless of the molecular species ingested, the molecular species absorbed by the gastrointestinal tract is tributyltin chloride (Schweinfurth and Gunzel 1987). The mechanism of toxic action of trialkyltins is thought to be the inhibition of a reaction in the energy transforming chain between electron transport and the formation of adenosine triphosphate (ATP) (McCollister and Schober 1975).

A summary of the acute oral toxicity of triphenyltin compounds to four commonly used laboratory animals is presented in Appendix K. The oral LD_{50} for rats ranged from 110 to 491 $mg \cdot kg^{-1}$ body weight. Within the intestine, the major molecular species was triphenyltin hydroxide, regardless of the triphenyltin anion ingested. The oxide of triphenyltin was less toxic, and the possible incidental formation of this compound in administered oil solutions of the hydroxide is thought to be the reason for the observed variation in toxicity test results. Guinea pigs are one of the most sensitive mammals to triphenyltin compounds. Oral administration produced slow death with weakness, anorexia, rough coat, diarrhea, staggering, and reddish lachrymal fluid preceding death in coma. The main site of action for triphenyltin toxicity appears to be the central nervous system (Bock 1981). *In vitro* studies show that triphenyltin compounds inhibit oxidative phosphorylation in liver mitochondria and adenosine triphosphatase (ATPase) activity of brain microsomes. The inhibition of oxidative phosphorylation was accompanied by changes in the selective permeability of mitochondrial membranes (McCollister and Schober 1975).

Biochemical and pharmacological studies on the mechanism of action of tricyclohexyltin hydroxide show symptoms in experimental animals similar to those of triphenyltin compounds. The main site of action appears to be the central nervous system (McCollister and Schober 1975).

Uptake and Metabolism

In vivo and *in vitro* studies of the mammalian metabolism of tributyltin acetate have indicated the production of hydroxybutyltin derivatives. These metabolites undergo destannylation to form dibutyltin derivatives, butanol, butene, and the corresponding ketone (Kimmel *et al.* 1977). The observed sequential dealkylation of tributyltin from tri- to di- to monobutyltin and then to inorganic tin generally appears to operate in both mammalian and avian systems (NRCC 1985).

Uptake studies conducted on rats with radioactive tin as triphenyltin chloride demonstrated that 80%–88% of the orally administered triphenyltin was eliminated in feces and urine within 7 d. Following ingestion, concentrations of triphenyltin were always higher in the gastrointestinal tract, followed by the liver and kidneys. The radioactive tin eliminated from the body was not always differentiated as to inorganic or organic tin in these experiments, but other experiments have demonstrated that the amount of triphenyltin appears to decrease with increasing time. This suggests metabolism and possibly microbial decomposition within the gut. Dietary levels of 5–25 $mg \cdot kg^{-1}$ do not lead to triphenyltin accumulation (Bock 1981).

Metabolism of triphenyltin in the liver does not occur through the mixed-function oxygenase system. Studies of triphenyltin breakdown after oral and intraperitoneal administration showed little change in the parent compound prior to elimination from the body (Bock 1981).

Tricyclohexyltin is excreted from the bodies of test animals primarily in the feces. Rats receiving a single oral dose of ^{119}Sn tricyclohexyltin exhibited recoverable radioactivity in the excreta 10 d after dosing. Most of the activity (97.5%–98.1%) occurred in the feces, with very little activity in the urine. The majority of the tricyclohexyltin dose (75%–85%) was excreted in the first 4 d after dosing. These studies led the authors to conclude that tricyclohexyltin passes through the intestinal tract with very little absorption (McCollister and Schober 1975).

Physiological and Biochemical Effects

Depressed immunological responses in mammals have been observed after exposure to dialkyltin compounds. Specifically, dipropyl-, dibutyl-, and dioctyltin compounds caused dose-related decreases in the weights of thymus, spleen, and lymph nodes in rats after several weeks of ingestion. As a consequence, the immune response of these rats was depressed. Triorganotin compounds, particularly tripropyl-, tributyl-, and triphenyltins, are also known to have immunotoxic properties generally characterized by suppressed immune responses to infectious agents. Higher trialkyltin homologues such as trihexyl- or trioctyltin have either a limited or unobservable effect on the thymus and related immunological responses. Possible immunotoxic properties of trimethyl- or triethyltins are probably masked by their extreme neurotoxicity (Snoeij *et al.* 1987a).

Long-term, sublethal studies of tributyltin ingestion demonstrated that the main organs affected were those of the lymphatic system. Thymus atrophy was particularly evident in 4- and 13-week feeding studies using juvenile rats. Thymus-dependent immune responses were also impaired at dietary levels of 5 and 50 mg•kg^{-1}. Higher dietary concentrations (i.e., 80 mg•kg^{-1}) produced hormonal changes (Schweinfurth and Gunzel 1987).

Hepatotoxic studies of organotins are primarily concerned with dibutyltin compounds and damage (e.g., inflammation, lesion) to the bile duct that may result in peritonitis and pancreatitis. Similar damage is also caused by diethyl-, dipropyl-, diphenyl-, and dihexyltin compounds, but to a lesser degree. Bile duct damage also occurred in rats chronically exposed to tributyltin compounds (Snoeij *et al.* 1987a). Death and inflammation of the hepatic bile duct occurred in 9 of 24 rat pups orally exposed to 3 mg•kg^{-1} tributyltin acetate over a period of 28 d (Mushak *et al.* 1982).

Neurotoxic effects induced by organotins appear limited to trimethyl- and triethyltin. Symptoms of neurological damage in rats treated with dimethyl-, diethyl-, or any of the higher trialkyltin homologues have not been observed (Snoeij *et al.* 1987a).

Japanese quail (*Coturnix japonica*) are less sensitive than rats to tributyltin ingestion, with dietary levels of 450 mg•kg^{-1} failing to produce effects. Long-term ingestion of tributyltin does not produce distinctive central nervous system damage, as occurs with methyltin (Kimmel *et al.* 1977).

Mutagenic, Teratogenic, and Carcinogenic Effects

Bis(tributyltin) oxide has not been shown to induce point mutations or DNA damage in the majority of the *in vitro* microbial and mammalian cell test systems tested thus far. One report of a mutagenic response (Davis *et al.* 1987) could not be confirmed during a re-evaluation of the data (Schweinfurth and Gunzel 1987). In addition, six tributyltin esters produced negative results with the Ames test.

Maternal doses as high as 6 mg•kg^{-1} bis(tributyltin) oxide did not produce teratogenic effects in mice. Doses of 11.7 mg•kg^{-1} and higher have produced maternal toxicity and are thought to have caused an increase in the frequency of cleft palates in the offspring of the surviving females. Conclusive evidence, however, is lacking. The NOEL for maternal toxicity and embryo toxicity/fetal toxicity in rabbits administered bis(tributyltin) oxide on gestation days 6–18 was 1.0 mg•kg^{-1}. Teratogenic effects were not reported at higher levels that were found to cause maternal toxicity (Schweinfurth and Gunzel 1987).

Two-year bis(tributyltin) oxide feeding studies in rats showed an increase in the incidence of some benign tumours that normally have a high background level. This increase was believed to be due to bis(tributyltin) oxide interference with the normal physiology of the rats, rather than any genotoxic mechanism. Confirmation of a carcinogenic response to the ingestion of bis(tributyltin) oxide is lacking (Schweinfurth and Gunzel 1987).

Triphenyltin acetate orally administered to mice from 7 d to 14 weeks of age at the maximum tolerated dose (0.464 mg•kg^{-1}) did not have a significant effect on tumour incidence (Bock 1981). Triphenyltin hydroxide produced teratogenic effects in rats via ingestion. However, a NOEL could not be determined from the available data. Immunotoxic effects and reproductive effects were also produced by this compound. A three-generation study that derived a NOEL of 0.25 mg•kg^{-1}•d^{-1} was classified as not acceptable, as only summary data were submitted (U.S. EPA 1984).

Toxicity to Non-target Crops

Most of the available information related to organotin toxicity to terrestrial plants concerns the triphenyltin group of compounds (Appendix M). The fungicidal properties of this group have been recognized for over 40 years. However, use in agricultural pest control seemed impractical for a number of years because of the high phytotoxic characteristics of these compounds. Triphenyltin acetate, released commercially in 1954, was one of the first foliar fungicides to be effective against several fungi and yet of sufficiently low phytotoxicity for protection of the cultivated plant. However, prevention of damage to cultivated plants is dependent on the use of suitable formulations for particular plant species and proper dosage levels (Bock 1981).

A review of the information related to the phytotoxicity of different triphenyltin fungicides (Bock 1981) was impaired by a lack of data regarding formulations. The conclusion reached by Bock (1981) was that the phytotoxicity experiments using triphenyltin compounds were subject to varying degrees of uncertainty and thus are difficult to compare. The following factors were influential in the phytotoxicity of triphenyltin compounds: (1) the associated anion, (2) the antagonistic or synergistic effects of other compounds in the formulation, (3) the pH of the formulated liquid, (4) the solubility of the specific triphenyltin used, and (5) the particle size of the suspension. The associated anion was especially important, as triphenyltin chlorides, sulphates, acetates, and hydroxides are very phytotoxic. By comparison, the triphenyltin mono- and dithiocarbamates provided effective antifungal activity but were generally safe from the standpoint of phytotoxicity (Chandra *et al.* 1987).

Almost all of the phytotoxicity data for phenyltins are restricted to foliar applications. Phytotoxicity information related to root uptake is scarce, perhaps because of the strong adsorption of phenyltin compounds to soil and consequent reduction in bioavailability. Little information is available on the foliar phytotoxicity of other organotins. Tripropyltin acetate and several tributyltins have been found to be more phytotoxic than the triphenyltin acetate and hydroxides (Bock 1981). *In vitro* studies of isolated chloroplasts demonstrated an inhibition of photophosphorylation by trialkyltin and triphenyltin compounds (Watling and Selwyn 1972; Watling-Payne and Selwyn 1974; Gould 1976).

RECOMMENDED WATER QUALITY GUIDELINES

Raw Water for Drinking Water Supply

The Federal–Provincial Subcommittee on Drinking Water of the Federal–Provincial Advisory Committee on Environmental and Occupational Health has not recommended guidelines for drinking water for any of the organotin compounds (Health and Welfare Canada 1989). Until such guidelines are available, no guidelines for organotin compounds in raw water for drinking water supply will be attempted.

Recreation and Aesthetics

Recreational water can be aesthetically impaired by an offensive odour, taste, or colour. Although vapours from concentrated ethyltins "have a powerfully pungent odour" (Zuckerman *et al.* 1978), we found no evidence that this group of compounds has ever been detected in natural waters. Schweinfurth and Gunzel (1987) noted that the undiluted technical active ingredient tributyltin is severely irritating to the skin of experimental animals and to humans. Tributyltin paint formulations have also been found to cause skin and eye irritation in rabbits. However, it is unlikely that the tributyltin concentrations used in paint formulations would ever be found in waters used for recreational purposes. No published data on the organoleptic effects of any other organotins in water or in fish flesh were found. Therefore, Canadian water quality guidelines for this water use are not attempted.

Aquatic biota have been found to be relatively sensitive to low levels of tributyltin and triphenyltin, and guidelines or interim guidelines have been developed. Water containing organotin compounds at concentrations that could potentially affect recreational use would already be severely impaired for use by aquatic organisms. As it is the aim of the Canadian Council of Ministers of the Environment (CCME) to protect the most sensitive water uses in preparing Canadian water quality guidelines, no guidelines for recreational water quality and aesthetics are recommended for any organotins. Although methyltins and other butyltins have been detected in environmental samples in Canada, there is no evidence to indicate that recreational water quality and aesthetics were adversely affected.

Aquatic Life

Freshwater Aquatic Life

No Canadian water quality guidelines or interim Canadian water quality guidelines for the protection of freshwater aquatic life are recommended for organotin compounds other than tributyltin and triphenyltin. For compounds other than tributyltin and triphenyltin, the data considered in this report did not meet the minimum data set requirements required for developing guidelines (Appendix N-1) (CCREM 1987a).

An interim Canadian water quality guideline of 0.008 $\mu g \cdot L^{-1}$ tributyltin is recommended for the protection and maintenance of freshwater aquatic life. This level was derived by applying a safety factor of 10 to the lowest reported chronic effect level, a 33-d LOEL of 0.08 $\mu g \cdot L^{-1}$ tributyltin for growth of post-hatch fathead minnows (*Pimephales promelas*) (Brooke *et al.* 1986). The 90-d LOEL of 0.031 $\mu g \cdot L^{-1}$ tributyltin for histopathological changes in the guppy (*Poecilia reticulata*) (Wester and Canton 1987) was not used to derive the interim guideline because this fish species is not native to Canada. The data set considered in this report did not include any primary studies for tributyltin effects on freshwater plants, nor were there sufficient primary chronic data for freshwater fish and invertebrates (Appendix N-1). Therefore, there are insufficient data to proceed with full guideline development, and the 0.008 $\mu g \cdot L^{-1}$ level for tributyltin is recommended as an interim guideline. Based on the available primary and secondary toxicity information, the recommended guideline should provide protection for all freshwater aquatic biota and all aquatic life stages (Fig. 6).

An interim Canadian water quality guideline of 0.02 $\mu g \cdot L^{-1}$ triphenyltin is recommended for the protection and maintenance of freshwater aquatic life. This level was derived by applying a safety factor of 10 to the lowest reported chronic effect level, a 30-d LOEL of 0.22 $\mu g \cdot L^{-1}$ triphenyltin for growth of fathead minnows (*Pimephales promelas*) (Jarvinen *et al.* 1988). No primary studies for triphenyltin exposure of freshwater invertebrates or plants were available, and thus there were insufficient data to proceed with full guideline development (Appendix N-1). Based on the available primary and secondary toxicity information, the recommended guideline should provide protection for all aquatic biota and all aquatic life stages (Fig. 7).

Marine Aquatic Life

There are insufficient data to recommend Canadian water quality guidelines for the protection and maintenance of marine aquatic life for any organotin compounds except tributyltin (Appendix N-2) (CCREM 1987a).

The available data indicate that the most sensitive marine organisms to tributyltin are spat of the oyster *Crassostrea gigas* (Lawler and Aldrich 1987). In a short-term experiment, spat exposed to 0.01 $\mu g \cdot L^{-1}$ bis(tributyltin) oxide were significantly less able to compensate for hypoxia, a frequent condition in the shallow estuarine breeding areas of this species. Also at 0.01 $\mu g \cdot L^{-1}$ bis(tributyltin) oxide, Laughlin *et al.* (1988) found growth inhibition occurred in the clam *Mercenaria mercenaria*. Therefore, a Canadian water quality guideline of 0.001 $\mu g \cdot L^{-1}$ tributyltin is recommended for the protection and maintenance of marine aquatic life. This value was derived by applying a safety margin of 10 to the above chronic value. All minimum data set requirements were met for this compound (Appendix N-2). The available toxicity information indicates that the guideline value of 0.001 $\mu g \cdot L^{-1}$ tributyltin should provide protection for all marine aquatic biota and aquatic life stages (Fig. 8).

Agriculture

Livestock Watering

Tributyltin

Acute toxicity studies are generally single-dose studies that are performed to characterize the effects after a single exposure to large amounts of the compound (e.g., after accidental ingestion). For oral ingestion of tributyltin, rat LD_{50} values ranged from 94 to 224 $mg \cdot kg^{-1}$ body weight and mice LD_{50} values ranged from 46 to 230 $mg \cdot kg^{-1}$ body weight (Appendix I). The inhalation and dermal routes of exposure are not of concern for livestock because tributyltin is not expected to occur at high levels for exposure via those routes (Schweinfurth and Gunzel 1987). Death and inflammation of the hepatic bile duct occurred in 9 of 24 rat pups orally exposed to 3 $mg \cdot kg^{-1}$ tributyltin acetate over a period of 28 d (Mushak *et al.* 1982) (Appendix J).

Canadian water quality guidelines for livestock water are calculated using maximum daily intake (MDI) rates, livestock body weights, and daily water intakes. The high water intake rates of lactating dairy cattle (up to 200 $L \cdot d^{-1}$) indicate that they will likely be the most sensitive animals to tributyltin in livestock water. Because livestock may also be exposed to tributyltin through food sources or other exposure routes, an assumed percentage of daily exposure through ingestion of drinking water of 20% is used in the calculation of the water quality guideline (NAS 1977). Therefore, the following calculation was performed in order to derive a Canadian water quality guideline for tributyltin for the protection and maintenance of livestock water:

Maximum Daily Intake = 3 $mg \cdot kg^{-1} \cdot d^{-1}$ (Mushak *et al.* 1982)
Safety Factor = 0.1 (for lifetime exposures) (CCREM 1987b)
Dairy Cattle Body Weight (maximum) = 820 kg (W. Buckley, Agriculture Canada, pers. com).
Daily Water Intake (maximum) = 200 $L \cdot d^{-1}$ (W. Buckley, Agriculture Canada, pers. com).
Relative Source Contribution (in water) = 20% (NAS 1977)
Canadian Water Quality Guideline = [(3 $mg \cdot kg^{-1} \cdot d^{-1}$ × 0.1 × 820 kg)/200 $L \cdot d^{-1}$] × 20%
= 0.25 $mg \cdot L^{-1}$ tributyltin

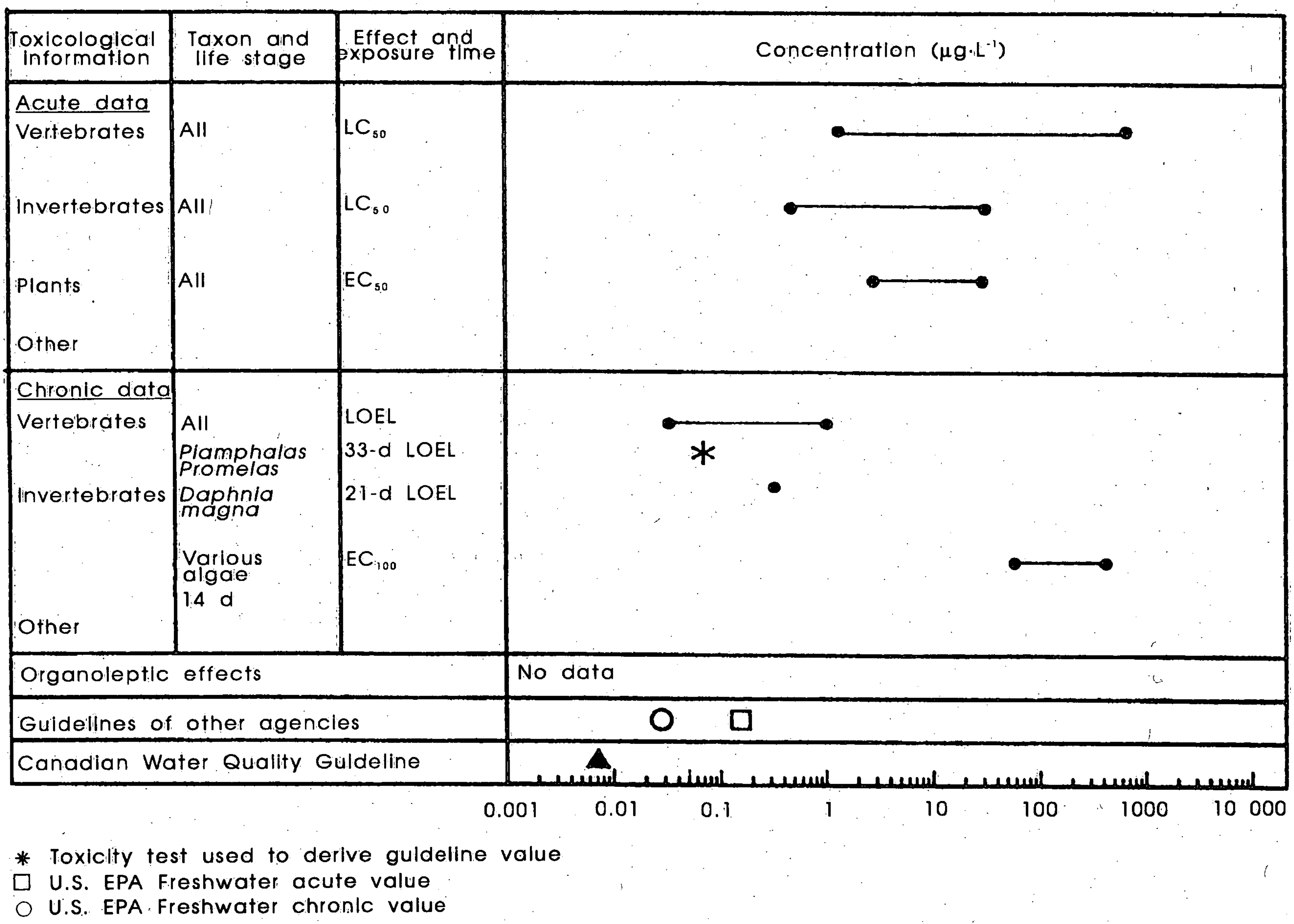


Figure 6. Guideline derivation graph for tributyltin for the protection of freshwater aquatic life.

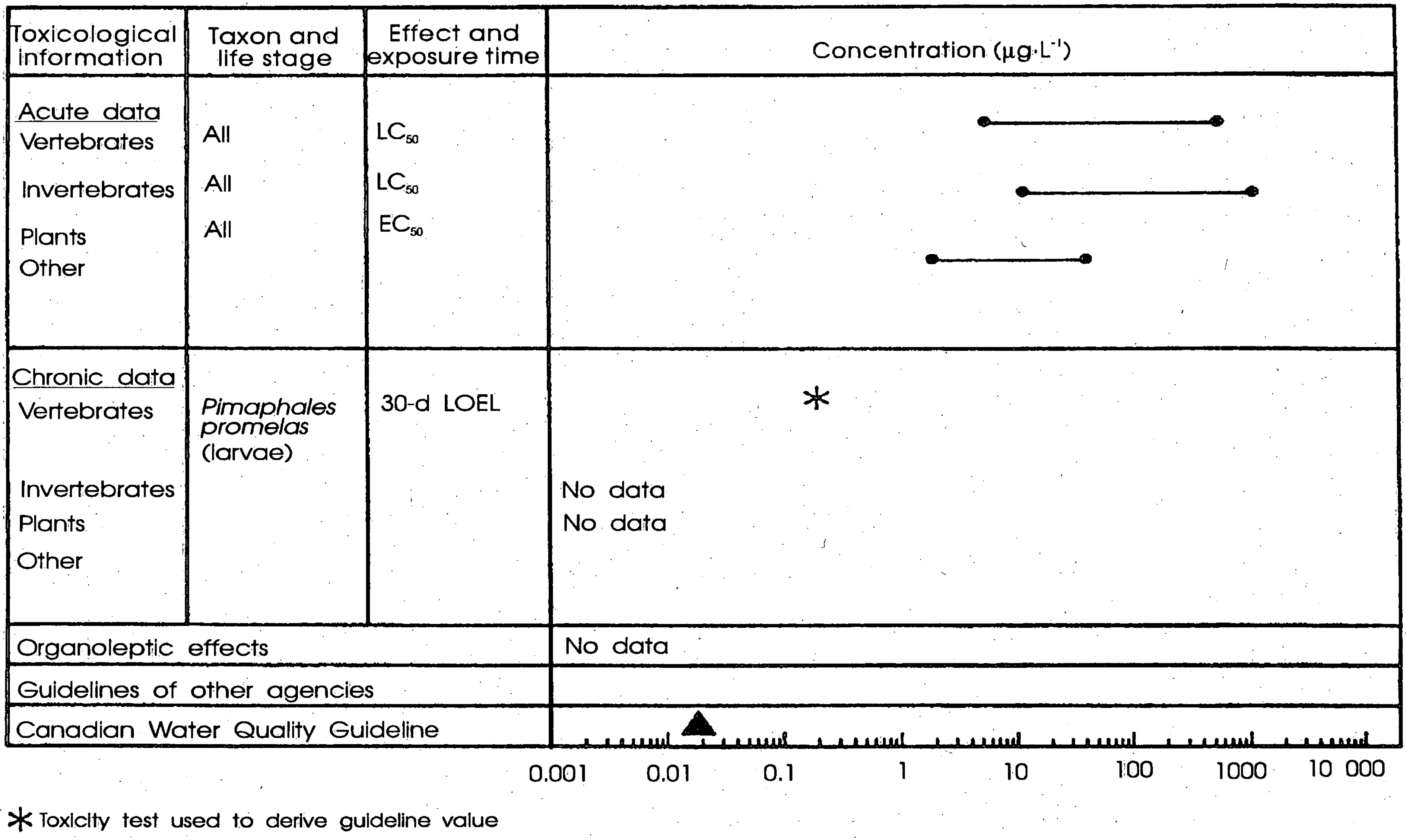


Figure 7. Guideline derivation graph for triphenyltin for the protection of freshwater aquatic life.

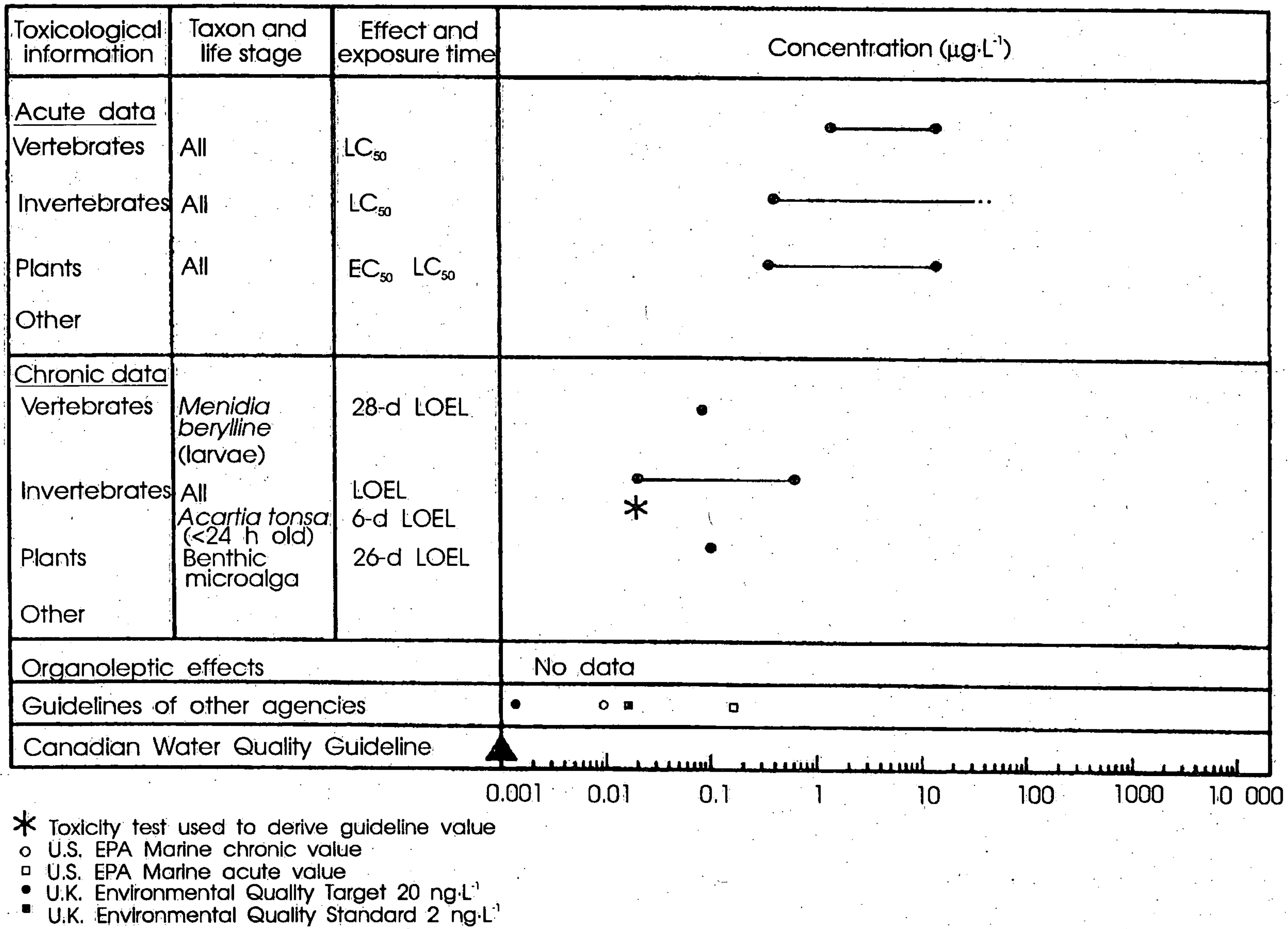


Figure 8. Guideline derivation graph for tributyltin for the protection of marine aquatic life.

Triphenyltin

For oral ingestion of triphenyltin, acute LD_{50}s for rats have been shown to range from 110 to 491 mg•kg^{-1} body weight (Appendix K). For mice, the LD_{50} range was found to be 80–1000 mg•kg^{-1} body weight, whereas guinea pigs and rabbits had LD_{50} ranges of 10–41.2 and 30–140 mg•kg^{-1} body weight, respectively. Long-term ingestion studies with several mammalian species have indicated that rats, guinea pigs, and dogs have a similar sensitivity to triphenyltin in the diet (Bock 1981). The most sensitive long-term response was observed in guinea pigs exposed to triphenyltin acetate in their diet for a period of 2 years (Bock 1981). In this study, significant histopathological changes were observed in the cells of the liver and heart at 10 mg•kg^{-1}•d^{-1} triphenyltin. Using this value as the maximum daily intake and the same guideline derivation procedure described above for tributyltin, a Canadian water quality guideline for livestock water of 0.8 mg•L^{-1} triphenyltin is recommended.

Tricyclohexyltin

Studies on the toxicity of tricyclohexyltin hydroxide show effects in experimental animals similar to those of triphenyltin. An acute oral LD_{50} of 540 mg•kg^{-1} has been shown for rats (McCollister and Schober 1975). Long-term (2-year) dietary studies with dogs and rats indicated slightly decreased rates of growth at 3 and 6 mg•kg^{-1}•d^{-1}, respectively (McCollister and Schober 1975). Using the results of the long-term dietary study on dogs and the same guideline derivation method described above for tributyltin, an interim Canadian water quality guideline of 0.25 mg•L^{-1} tricyclohexyltin is recommended for the protection and maintenance of livestock water. This value is recommended as an interim guideline because the available toxicity data base for mammals, particularly concerning long-term feeding studies, is relatively small.

There is insufficient information available for the derivation of livestock watering guidelines for any other organotin compounds.

Irrigation Water

Triphenyltin

Triphenyltin compounds have been used extensively on various crops because of their fungicidal properties. However, triphenyltin compounds can be phytotoxic. The phytotoxicity of a preparation is dependent on the crop, the chemical formula of the active ingredient, the formulation, and climate (Bock 1981). As a result of deficiencies in the available data, comparative experiments aimed at establishing triphenyltin toxicity are subject to a great degree of uncertainty. Therefore, there were insufficient data to derive Canadian water quality guidelines for any organotin compounds for the protection and maintenance of irrigation water.

Industrial Water Supplies

To date, there is no indication that organotin compounds pose a threat to industrial water supplies. However, until a survey of industry requirements regarding water quality is conducted, development of Canadian water quality guidelines for industrial water supplies cannot be attempted. Such a survey is under way, and guideline development for this water use is planned for a future date.

DATA GAPS

Environmental Concentrations

Given recent changes to the regulatory status of organotins under the *Pest Control Products Act*, use patterns for organotin biocides have changed considerably during the past 3 years. No information is available regarding current volumes of use of organotin pesticides in Canada. This information is necessary to properly evaluate the environmental and human health risks posed by organotin compounds in the Canadian environment. Further, for organotin compounds other than the butyltins, few data are available regarding levels in water, sediments, or biota.

Environmental Fate and Persistence

The environmental fate and persistence of the butyltin compounds are fairly well understood. However, the importance of photolysis and anaerobic metabolism as potential processes for the removal of tributyltin from water needs to be clarified, especially with regard to the effects of salinity.

The major fate processes for the methyltin group of compounds have been investigated. However, the rates of reaction for most of these processes are not known; the persistence times of the methyltin compounds in various environmental compartments are also unknown. Therefore, the mobility of the methyltin compounds in the environment and the compartments in the aquatic environment in which these compounds are likely to be found cannot be assessed.

Little is known of the environmental fate and behaviour of the phenyltin group of compounds. The major fate processes and reaction end products remain to be investigated, particularly in the sediment compartment. The importance of salinity in the environmental fate and persistence of phenyltin compounds is virtually unknown.

Information regarding the environmental fate and behaviour of other organotin compounds is scattered and incomplete. However, these compounds are not likely of concern in Canada because of their limited usage in industry and agriculture.

Bioaccumulation

The major processes affecting the bioaccumulation of butyltin compounds in aquatic biota appear well understood. However, for methyltins, phenyltins, and other organotins, more studies are required to determine the bioaccumulation potential of these compounds in aquatic biota. In particular, the possibility that methyltin bioaccumulation in aquatic biota is partially due to biogenic methylation of inorganic tin requires further investigation. As well, bioaccumulation studies are required for freshwater and marine invertebrates and plants and marine fish for the phenyltin group of compounds.

Toxicity to Aquatic Biota

The specific toxicity data required to prepare Canadian water quality guidelines for the methyltin, butyltin, and phenyltin compounds in the freshwater and marine environments are outlined in Appendix N. In general, few primary or secondary studies are available for the mono- and diorganotins for fish, invertebrates, or plants. These compounds therefore require chronic exposure studies on a range of aquatic biota, including cold- and warm-water fish, two classes of invertebrates of which one is planktonic, and one plant or algal species, before freshwater aquatic life guidelines can be prepared. Before marine aquatic life guidelines can be developed for the mono- and diorganotin compounds and for triphenyltin, chronic exposure studies are required for three temperate fish species, two classes of invertebrate fish species, and one plant or algal species. The above information for freshwater and marine guidelines is also required to develop guidelines for trimethyltin. For the above studies to be accorded a primary ranking, as required for the development of Canadian water quality guidelines, the toxicity studies should be conducted under flow-through conditions with measured toxicant concentrations and an adequate reporting of experimental conditions and control treatment responses (see CCREM 1987a).

To elevate the interim freshwater guideline for tributyltin to full guideline status requires that chronic exposure studies be conducted for a cold-water fish species and a non-cladoceran invertebrate species, as well as an acute or chronic exposure study on a plant or algal species. In order to elevate the interim freshwater guideline for triphenyltin to full guideline status, the following are required: (1) two additional studies on fish species, including one cold-water species and one chronic effects study, (2) two chronic effects studies on two invertebrate species, and (3) one study on an algal or plant species. Additional studies required to develop a guideline for triphenyltin in marine waters include an acute or chronic study on a fish species and a chronic exposure study on a cladoceran species.

Toxicity to Livestock and Related Biota

There appears to be adequate information concerning the toxic effects of tributyltin and triphenyltin on livestock and related biota. The available data for tricyclohexyltin are somewhat variable and require further investigation. For all other organotin compounds, there is little available toxicity information.

Toxicity to Non-target Plants

Much of the available information for organotin toxicity effects on crop plants is over 20 years old and is not acceptable by current standards. Further, the available data for triphenyltin involved one or a few sprayings on a crop field at one dose level with little if any reporting of control responses and environmental conditions. To convert these data to a continuous-exposure water quality guideline for irrigation water involves numerous assumptions of unknown validity. Future studies should involve continuous exposures in irrigation water at a variety of dose levels. Few toxicity data were available for organotin compounds other than triphenyltin.

SUMMARY

Following an extensive evaluation of the published literature on organotins, Canadian water quality guidelines were derived (Table 4). The background information on organotins in terms of their uses, physical and chemical properties, environmental concentrations, fate and persistence, bioaccumulation potential, and toxic effects on freshwater and marine biota, non-target crops, and livestock was reviewed. The rationale employed for the development of the recommended guidelines was summarized.

Table 4. Recommended Water Quality Guidelines for Organotins

Uses	Guidelines
Raw water for drinking water supply	No recommended guideline
Recreational water quality and aesthetics	No recommended guideline
Aquatic life	
Freshwater	0.008 $\mu g \cdot L^{-1}$ tributyltin cation (interim)
	0.02 $\mu g \cdot L^{-1}$ tributyltin cation (interim)
Marine	0.001 $\mu g \cdot L^{-1}$ tributyltin cation
Agricultural water supply	
Livestock water	250 $\mu g \cdot L^{-1}$ tributyltin cation 800 $\mu g \cdot L^{-1}$ triphenyltin cation 250 $\mu g \cdot L^{-1}$ tricyclohexyltin cation (interim)
Irrigation	No recommended guideline
Industrial water supply	No recommended guideline

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Appendix A
Physical and Chemical Properties and Uses of Organotin Compounds

Table A-1. Physical and Chemical Properties and Uses of Organotin Compounds

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
MONOORGANOTINS					
Bis(butyltin) trisulphide	$(C_4H_9)_2Sn_2S_3$	895.28			S
Monobutyltin trichloride	$(C_4H_9)SnCl_3$	282.08	Colourless liquid; BP = 102	Slightly sol	C,S,2,10,11
Monoethyltin trichloride	$(C_2H_5)SnCl_3$	254.11			C
Monooctyltin trichloride	$(C_8H_{17})SnCl_3$	338.12	Colourless liquid; MP = -63; BP = 98		11
Monophenyltin tribromide	$(C_6H_5)SnBr_3$	435.45			C
Monophenyltin trichloride	$(C_6H_5)SnCl_3$	302.10			C
DIORGANOTINS					
Bis(dibutylacetatotin) oxide	$[(C_4H_9)_2SnOOC_2H_3]_2O$	599.58			C,S
Bis(dibutylchlorotin) oxide	$[(C_4H_9)_2SnClO]_2O$	1104.88	MP = 110–112		C
Bis(dimethylacetatotin) oxide	$[(CH_3)_2SnOOC_2H_3]_2O$	431.46	MP = 236		S
Bis(dipropylchlorotin) oxide	$[(C_3H_7)_2SnClO]_2O$	992.80	MP = 121–122		C
Bis(dipropylpropionatotin) oxide	$[(C_3H_7)_2SnOOC_2H_3]_2O$	543.54			C
Dibutyltin bis(isooctylthioglycolate)	$(C_4H_9)_2Sn(SCH_2CO_2C_8H_{17})_2$	639.11	Slightly yellow liquid		C,S,B,1,3
Dibutyltin diacetate	$(C_4H_9)_2Sn(OOC_2H_3)_2$	350.81	Colourless liquid; MP = 10; BP = 142–145	Insol	C,S,B,3
Dibutyltin diacetylacetone	$(C_4H_9)_2Sn[(CH_3CO)_2CH]_2$	430.87			S
Dibutyltin dibenzylsulphide	$(C_4H_9)_2Sn(SCH_2C_6H_5)_2$	479.03			S
Dibutyltin dibromide	$(C_4H_9)_2SnBr_2$	392.74	Small needles; MP = 20; BP = 118–170	Insol	C

Source: Adapted from NIOSH 1977, with additional data from Tsuda *et al.* 1986b(1), NRCC 1985(2), Laughlin *et al.* 1986b(3), Maguire *et al.* 1983(4), R. Chenier, 1990, Commercial Chemicals Branch Environment Canada, pers. com.(5), and Worthing and Walker 1987(6).

Uses
C = catalyst; S = stabilizer; B = biocide; 1 = solvent; 2 = used in flame-resistant polyester; 3 = used in metal plating; 4 = gasoline additive; 5 = used in solder; 6 = antifogging agent; 7 = used to improve adhesion of polychloroprenes; 8 = wood preservative; 9 = antiwear additive; 10 = curing agent; 11 = used in thermal or electrical coatings; 12 = used in water-repellant coating; 13 = antioxidant or corrosion inhibitor; 14 = photographic film additive

Characteristics
BCF = bioconcentration factor; Sol = soluble; Insol = insoluble; BP = boiling point (°C); MP = melting point (°C); VP = vapour pressure in mmHg; K_{ow} = octanol/water partition coefficient

Table A-1. Continued

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
DIORGANOTINS (cont'd)					
Dibutyltin dibutoxide	$(C_4H_9)_2Sn(OC_4H_9)_2$	378.85			C
Dibutyltin dicaprylate	$(C_4H_9)_2Sn(O_2CC_7H_{15})_2$	518.93	MP = -22		C,S,B
Dibutyltin dichloride	$(C_4H_9)_2SnCl_2$	303.83	White needles; MP = 113.6; BP = 142; K_{ow} = 9.33(1)	Sol (hot)	C,S,B,10
Dibutyltin diethoxide	$(C_4H_9)_2Sn(OC_2H_5)_2$	322.81			C,S
Dibutyltin di(2-ethylhexoate)	$(C_4H_9)_2Sn(O_2CCHC_2H_5C_4H_9)_2$	518.93			C,S,B
Dibutyltin difluoride	$(C_4H_9)_2SnF_2$	270.77			S,B
Dibutyltin diiodide	$(C_4H_9)_2SnI_2$	486.57			2
Dibutyltin dilaurate	$(C_4H_9)_2Sn(OOCC_{11}H_{23})_2$	631.55	Liquid or low-MP solid depending on type and purity; MP = 27; K_{ow} = 1318(1)		C,S,B,13
Dibutyltin dimethoxide	$(C_4H_9)_2Sn(OCH_3)_2$	294.79			C,2,12
Dibutyltin di(methylmaleate)	$(C_4H_9)_2Sn(O_2CCH{:}CHCO_2CH_3)_2$	490.87			
Dibutyltin distearate	$(C_4H_9)_2Sn(O_2CC_{17}H_3)_2$	799.13			C,S,B
Dibutyltin malate	$(C_4H_9)SnO_2CCH{:}CHCO_2$	346.81	White powder; K_{ow} = 18.6(1)	Insol	C,S,13
Dibutyltin methoxide acetate	$(C_4H_9)_2Sn(OOC_2H_3)OCH_3$	322.80			C
Dibutyltin oxide	$(C_4H_9)_2SnO$	248.92	White powder	Insol	C,S,2,7,10,11
Diethyltin dibenzoate	$(C_2H_5)_2Sn(OOCC_6H_5)_2$	418.89			S
Diethyltin dicaprylate	$(C_2H_5)_2Sn(O_2CC_7H_{15})_2$	462.89			C
Diethyltin dichloride	$(C_2H_5)_2SnCl_2$	247.63			C,S,5
Diethyltin dimethoxide	$(C_2H_5)_2Sn(OCH_3)_2$	238.75			C
Diethyltin oxide	$(C_2H_5)_2SnO$	192.81	White powder; infusible	Insol	C,B
Diethyltin sulphide	$(C_2H_5)_2SnS$	208.79	Slightly yellow liquid		C,S,B,9,13

Table A-1. Continued

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
DIORGANOTINS (cont'd)					
Dimethyltin dibutylsulphide	$(CH_3)_2Sn(SC_4H_9)_2$	326.91			C,S,B
Dimethyltin dihydride	$(CH_3)_2SnH_2$	150.71			C
Dimethyltin dimethoxide	$(CH_3)_2Sn(OCH_3)_2$	210.73	MP = 86		12
Dimethyltin oxide	$(CH_3)_2SnO$	164.70	White powder	Insol	C
Dimethyltin sulphide	$(CH_3)_2SnS$	180.78	MP = 148		S
Dioctyltin dichloride	$(C_8H_{17})_2SnCl_2$	415.75			C,2
Dioctyltin oxide	$(C_8H_{17})_2SnO$	360.85			C,S
Diphenyltin dibromide	$(C_6H_5)_2SnBr_2$	432.72	Colourless crystals; MP = 38; BP = 230		C
Diphenyltin dichloride	$(C_6H_5)_2SnCl_2$	343.81	Colourless crystals; MP = 42; BP = 333–337	About 50 mg•L^{-1} at 20°C	C,13
Diphenyltin oxide	$(C_6H_5)_2SnO$	288.90	Colourless powder		S
TRIORGANOTINS					
Bis(tributyltin) oxide	$[(C_4H_9)_3Sn]_2O$	595.62	Yellow liquid; BP = 254; BCF = 125; K_{ow} = 1996(2); K_{ow} = 4592(1); K_{ow} = 200(3); K_{ow} = 2185(3); K_{ow} = 1550(3); K_{ow} = 5500(3); K_{ow} = 7000(3); VP = 6.4 x 10^{-7}(4)	Insol	C,B,2,8,10,12,13
Bis(triethyltin) oxide	$[(C_2H_5)_3Sn]_2O$	427.50			C
Bis(triisobutyltin) oxide	$[(C_4H_9)_3Sn]_2O$	595.62			B
Bis(triphenyltin) oxide	$[(C_6H_5)_3Sn]_2O$	715.74			C
Bis(tripropyltin) oxide	$[(C_3H_7)_3Sn]_2O$	511.56			B
N,N-bis(tributyltin) diphenylurea	$[(C_4H_9)_3SnNC_6H_5]_2CO$	789.77			C,S,B
N,O-bis(tributyltin) phenylcarbamate	$(C_4H_9)_3SnNC_6H_5CO_2Sn(C_4H_9)_3$	714.70			C,S,B
Tributyltin acetate	$(C_4H_9)_3Sn(OOC_2H_3)$	349.08	White, waxy solid; BP = 80–83; K_{ow} = 281.9(1)	Insol	B,2,8,10,11

Table A-1. Continued

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
TRIORGANOTINS (cont'd)					
Tributyltin benzoate	$(C_4H_9)_3SnOOCC_6H_5$	410.88			B
Tributyltin borate	$(C_4H_9)_3SnBO_2$	332.62			B,8
Tributyltin butoxide	$(C_4H_9)_3SnOC_4H_9$	362.85			C
Tributyltin chloride	$(C_4H_9)_3SnCl$	326.16	K_{ow} = 1310(2); K_{ow} = 118(1); K_{ow} = 1300(3); BCF = 79(2)		B
Tributyltin fluoride	$(C_4H_9)_3SnF$	308.81	K_{ow} = 1580(2); K_{ow} = 1400(3); BP = 341–342; BCF = 100(2)		S
Tributyltin hydride	$(C_4H_9)_3SnH$	290.81			C,B,5
Tributyltin isocyanate	$(C_4H_9)_3SnNCO$	331.83			C,B
Tributyltin isothiocyanate	$(C_4H_9)_3SnNCS$	347.89	BP = 150–153		C,B
Tributyltin laurate	$(C_4H_9)_3SnO_2CC_{11}H_{23}$	488.93			C,S,B
Tributyltin methoxide	$(C_4H_9)_3SnOCH_3$	320.82			C,S,B
Tributyltin oleate	$(C_4H_9)_3SnO_2C(CH_2)_7CH{:}CHC_8H_{17}$	570.99			C
Tributyltin phenoxide	$(C_4H_9)_3SnOC_6H_5$	382.87			C
Tributyltin methacrylate	$C_{16}H_{32}O_2Sn$	375.12			B(5)
Tributyltin maleate	$C_{16}H_{30}O_4Sn$	405.10(5)			
Fenbutatin oxide	$C_{60}H_{78}OSn_2$	1052.66(5)	MP = 138–139(6)	0.005 mg•L^{-1} at 23°C(6)	B(6)
Tricyclohexyltin hydride	$(C_6H_{11})_3SnH$	368.87	BP = 147–150		C
Tricyclohexyltin hydroxide	$(C_6H_{11})_3SnOH$	384.87	K_{ow} = 4.3(2); BCF = 1000(2)		B
Tricyclopropyltin chloride	$(C_3H_5)_3SnCl$	277.41			B
Triethyltin acetate	$(C_2H_5)_3Sn(OOC_2H_3)$	264.77			C,B,8
Triethyltin azide	$(C_2H_5)_3SnN_3$	247.93			B,9

Table A-1. Continued

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
TRIORGANOTINS (cont'd)					
Triethyltin chloride	$(C_2H_5)_3SnCl$	241.33	Colourless liquid; MP = 15.8; 1 BP = 208–210	Sol	C,B
Triethyltin hydride	$(C_2H_5)_3SnH$	206.75			C
Triethyltin isocyanate	$(C_2H_5)_3SnNCO$	247.77			C,B
Triethyltin methoxide	$(C_2H_5)_3SnOCH_3$	236.76			S
Triethyltin hydroxide	$(C_2H_5)_3SnOH$	222.88			B
Trihexyltin chloride	$(C_6H_{13})_3SnCl$	409.32			12
Triisobutyltin chloride	$(C_4H_9)_3SnCl$	325.49	MP = 30.2; BP = 174		B
Triisopropyltin chloride	$(C_3H_7)_3SnCl$	283.41	K_{ow} = 50.12(2); BP = 134–137; BCF = 5.6(2)		B
Triisopropyltin hydride	$(C_3H_7)_3SnH$	248.78	BP = 68–70		C
Trimethyltin bromide	$(CH_3)_3SnBr$	243.70	Colourless crystals or liquid; MP = 27; BP = 165	Sol	C
Trimethyltin chloride	$(CH_3)_3SnCl$	199.24	Colourless crystals; MP = 27; BP = 154; Kow = 0.00125(2)	Slightly sol	C
Trimethyltin hydride	$(CH_3)_3SnH$	164.80	Colourless, oily liquid; BP = 59–61	Slightly sol	C
Trimethyltin hydroxide	$(CH_3)_3SnOH$	180.72	MP = 118		C,B,12
Triphenyltin acetate	$(C_6H_5)_3Sn(OOC_2H_3)$	408.89	MP = 118	28 mg•L^{-1} at 20°C	B,8
Triphenyltin bromide	$(C_6H_5)_3SnBr$	429.92	Colourless crystals; MP = 120.5; BP = 249	Insol	C,B
Triphenyltin chloride	$(C_6H_5)_3SnCl$	385.46	Colourless crystals; K_{ow} = 1259(2); K_{ow} = 128.8(1); BCF = 630(2); MP = 106; BP = 240	40 mg•L^{-1} at 20°C 78 mg•L^{-1} at 30°C	B,13,14
Triphenyltin fluoride	$(C_6H_5)_3SnF$	369.01	Fine prisms; MP = 357	Insol	B
Triphenyltin hydroxide	$(C_6H_5)_3SnOH$	367.02	White powder; MP = 118	8 mg•L^{-1} at 20°C	C,B,2,10
Triphenyltin isothiocyanate	$(C_6H_5)_3SnNCS$	407.95	MP = 171–172		9
Triphenyltin methoxide	$(C_6H_5)_3OCH_3$	380.88	MP = 171–172		B

Table A-1. Continued

Compound	Molecular formula	Molecular weight	Physical appearance and environmental coefficients	Water solubility	Uses
TRIORGANOTINS (cont'd)					
Tripropyltin chloride	$(C_3H_7)_3SnCl$	283.41	Colourless liquid; MP = -23.5; BP = 123		B
Tripropyltin fluoride	$(C_3H_7)_3SnF$	266.96	Flat prisms; MP = 275		B
Tripropyltin hydride	$(C_3H_7)_3SnH$	248.78			C
Tris(2-cyanoethyl)tin acetate	$(NCCH_2CH_2)_3Sn(OOC_2H_3)$	339.80			S,B
Tris(tributyltin) borate	$[(C_4H_9)_3Sn]_3BO_3$	928.24			B,8
Tris(tripropyltin) borate	$[(C_3H_7)_3Sn]_3BO_3$	803.15			B,8
TETRAORGANOTINS					
Allyltriphenyltin	$(C_6H_5)_3Sn(CH_2CHCH_2)$	390.90			C
Tetraallyltin	$(CH_2{:}CHCH_2)_4Sn$	282.81			C
Tetrabenzyltin	$(C_6H_5CH_2)_4Sn$	483.23	Colourless prisms; MP = 42–43	Insol	C
Tetrabutyloxyacetatoditin oxide	$Sn_4C_{40}H_{80}O_8[(Bu_2SnOAc)O(Bu_2SnOH)]_2$	1163.16			C,S
Tetraethyltin	$(C_2H_5)_4Sn$	234.94	Colourless liquid; MP = -112; BP = 181	Slightly sol	C,2,3
Tetraisopropyltin	$(C_3H_7)_4Sn$	291.05			C
Tetramethyltin	$(CH_3)_4Sn$	178.85	Colourless liquid; MP = -54.8; BP = 78	Insol	C,1
Tetrabutyltin	$(C_4H_9)_4Sn$	347.21	Colourless liquid (distinct unpleasant odour); MP = -97; BP = 145	Insol	C,S,B,1,2,4,5,7
Tetraoctyltin	$(C_8H_{17})_4Sn$	571.59	Liquid; BP = 268	Insol	1
Tetraphenyltin	$(C_6H_5)_4Sn$	427.12	Colourless, tetragonal crystals; MP = 226; BP = 420	Insol	C,S,5,6
Tetrapropyltin	$(C_3H_7)_4Sn$	291.05	Colourless liquid; BP = 222–225	Insol	C,3
Tetravinyltin	$(CH{:}CH_2)_4Sn$	226.87	Colourless liquid; BP = 55–57		C
Trimethylphenyltin	$(CH_3)_3Sn(C_6H_5)$	240.92	BP = 62–63		6

Appendix B
Concentrations of Organotin Compounds Reported in Surface Waters

Table B-1. Concentrations of Organotin Compounds Reported in Surface Waters

Medium	Concentration[1] ($ng \cdot L^{-1}$)	Location	Reference
MONOMETHYLTIN ($MeSn^{3+}$)			
Fresh water	nd–13.5	Florida, USA	Braman and Tompkins 1979
Fresh water	3.4–10	Lake Michigan, USA	Hodge *et al.* 1979
Fresh water	nd–1.6	Rivers in SE USA	Byrd and Andreae 1982
Fresh water	79	Rhine River, Germany	Byrd and Andreae 1982
Fresh water	nd–1220	Across Canada	Maguire *et al.* 1982, 1986
Rainwater	nd–5.6	California, USA	Tugrul *et al.* 1983
Rainwater	0.73–24.8	Florida, USA	Braman and Tompkins 1979
Estuarine water	nd–9.6	Florida, USA	Braman and Tompkins 1979
Seawater	nd–16.9	Florida, USA	Braman and Tompkins 1979
Seawater	nd–4.5	California, USA	Hodge *et al.* 1979
Seawater	nd–4.5	California, USA	Tugrul *et al.* 1983
Seawater	nd–23.5	Mediterranean Sea	Tugrul *et al.* 1983
DIMETHYLTIN (Me_2Sn^{2+})			
Fresh water	nd–9.4	Florida, USA	Braman and Tompkins 1979
Fresh water	nd–42.7	Lake Michigan, USA	Hodge *et al.* 1979
Fresh water	nd–3.9	Rivers in SE USA	Byrd and Andreae 1982
Fresh water	263.6	Rhine River, Germany	Byrd and Andreae 1982
Fresh water	0.5	Main River, Germany	Byrd and Andreae 1982
Fresh water	nd–320	Across Canada	Maguire *et al.* 1982, 1986
Rainwater	nd–6	Florida, USA	Braman and Tompkins 1979
Estuarine water	0.94–5.8	Florida, USA	Braman and Tompkins 1979
Estuarine water	<5–100	Baltimore Harbor, USA	Jackson *et al.* 1982
Seawater	0.8–8.8	Florida, USA	Braman and Tompkins 1979
Seawater	nd–30	California, USA	Hodge *et al.* 1979
Seawater	nd–31	San Diego Bay, USA	Tugrul *et al.* 1983
TRIMETHYLTIN (Me_3Sn^{+})			
Fresh water	nd–10.6	Florida, USA	Braman and Tompkins 1979
Fresh water	nd–248	Across Canada	Maguire *et al.* 1982, 1986

nd = not detected

det = detected, but not quantifiable

[1] Nanograms of organotin cation, except for tetraorganotins, which are not cationic.

Source: Adapted from Maguire 1987, with additional data.

Table B-1. Continued

Medium	Concentration[1] (ng•L^{-1})	Location	Reference
TRIMETHYLTIN (Me_3Sn^+) (cont'd)			
Fresh water	nd–2.3	Rivers in SE USA	Byrd and Andreae 1982
Fresh water	2.2	Rhine River, Germany	Byrd and Andreae 1982
Fresh water	0.4	Main River, Germany	Byrd and Andreae 1982
Rainwater	nd–1.5	Florida, USA	Braman and Tompkins 1979
Estuarine water	nd–5.6	Florida, USA	Braman and Tompkins 1979
Estuarine water	< 20	Baltimore Harbor, USA	Jackson *et al.* 1982
Seawater	nd–1.4	Florida, USA	Braman and Tompkins 1979
TETRAMETHYLTIN (Me_4Sn)			
Estuarine water	<10–300	Baltimore Harbor, USA	Jackson *et al.* 1982
MONOBUTYLTIN ($BuSn^{3+}$)			
Fresh water	13.7–760	Lake Michigan, USA	Hodge *et al.* 1979
Fresh water	nd–8500	Rivers and lakes in Ontario, Canada	Maguire *et al.* 1982
Fresh water	nd–168	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
Fresh water	nd–135	Toronto Harbour, Canada	Maguire and Tkacz 1985
Fresh water	nd–2800	Across Canada	Maguire *et al.* 1986
Fresh water	8–32	Lake Zurich and Swiss rivers	Mueller 1987
Freshwater surface microlayer	nd–100 200	Canadian rivers and lakes	Maguire and Tkacz 1987
Estuarine water	50–300	Baltimore Harbor, USA	Jackson *et al.* 1982
Estuarine water	nd–1.8	Tejo River estuary, Portugal	Andreae *et al.* 1983
Estuarine water	nd–188	Great Bay estuary, USA	Donard *et al.* 1986
Estuarine water	<2–18.9	Elizabeth River, Sarah Creek, Chesapeake Bay, USA	Unger *et al.* 1986
Estuarine water	<1.5–3	Tamar River, U.K.; Tejo River, Portugal; Delaware Bay, USA	Byrd and Andreae 1986
Estuarine water	21–750	Chesapeake Bay, USA	Matthias *et al.* 1986b
Estuarine water	<1–9.3	U.K. harbours, anchorages	Waldock *et al.* 1988
Estuarine surface microlayer	42–218	Great Bay estuary, USA	Donard *et al.* 1986
Estuarine surface microlayer	248	Baltimore Harbor, USA	Matthias *et al.* 1986a
Seawater	<1–210	Southern U.K.	Waldock *et al.* 1987b
Seawater	nd–30	San Diego Bay, USA	Valkirs *et al.* 1985b

Table B-1. Continued

Medium	Concentration[1] (ng•L^{-1})	Location	Reference
MONOBUTYLTIN ($BuSn^{3+}$) (cont'd)			
Seawater	nd–75	San Diego Bay, USA	Valkirs *et al.* 1986a
Seawater	<1–1.2	Esquimalt Harbour, Canada	Kaye *et al.* 1986
Seawater	12–45	San Diego Bay, USA	Valkirs *et al.* 1986b
Seawater	nd–19.7	San Diego Bay, USA	Seligman *et al.* 1986b
Seawater	nd–240	California coastal waters	Stallard *et al.* 1987
Sewage treatment plant effluent	127 500–3 825 000	Switzerland	Mueller 1987
DIBUTYLTIN (Bu_2Sn^{2+})			
Fresh water	7.7–1200	Lake Michigan, USA	Hodge *et al.* 1979
Fresh water	nd–7300	Rivers and lakes in Ontario, Canada	Maguire *et al.* 1982
Fresh water	nd–199	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
Fresh water	nd–196	Toronto Harbour, Canada	Maguire and Tkacz 1985
Fresh water	nd–2700	Across Canada	Maguire *et al.* 1986
Fresh water	4.7–31	Lake Zurich and Swiss rivers	Mueller 1987
Freshwater surface microlayer	nd–2 600 000	Rivers and lakes in Ontario,	Maguire *et al.* 1982 Canada
Freshwater surface microlayer	nd–10	St. Clair River, Canada	Maguire *et al.* 1985
Freshwater surface microlayer	nd–715 000	Canadian rivers and lakes	Maguire and Tkacz 1987
Estuarine water	nd–118	U.K. harbours, anchorages	Waldock *et al.* 1988
Estuarine water	2–131	Elizabeth River, Sarah Creek, Chesapeake Bay, USA	Unger *et al.* 1986
Estuarine water	5–666	N. Chesapeake Bay, USA	Hall *et al.* 1988b
Estuarine water	<4–539	Chesapeake Bay, USA	Matthias *et al.* 1986b
Estuarine water	nd–59	Estuaries in England	Ebdon *et al.* 1988
Estuarine water	24–145	Chesapeake Bay, USA	Hall *et al.* 1987
Estuarine water	nd–39	Chesapeake Bay, USA	Olson and Brinckman 1986
Estuarine water	<10–129	Chesapeake Bay, USA	Batiuk 1987
Estuarine surface microlayer	178	Baltimore Harbor, Annapolis marina, Chesapeake Bay, USA	Matthias *et al.* 1986a
Estuarine surface microlayer	nd–1200	Chesapeake Bay, USA	Hall *et al.* 1987
Seawater	det–294	Sutton Harbor, U.K.	Waldock *et al.* 1987b
Seawater	39–118	San Diego Bay, USA	Valkirs *et al.* 1985b

Table B-1. Continued

Medium	Concentration[1] (ng•L^{-1})	Location	Reference
DIBUTYLTIN (Bu_2Sn^{2+}) (cont'd)			
Seawater	7.8–294	Baltimore Harbor, Annapolis marina, San Diego Bay, USA	Matthias *et al.* 1986a
Seawater	nd–392	San Diego Bay, USA	Valkirs *et al.* 1986a
Seawater	<2–1.6	Esquimalt Harbor, Canada	Kaye *et al.* 1986
Seawater	235–510	San Diego Bay, USA	Valkirs *et al.* 1986a
Seawater	2.7–114	San Diego Bay, USA	Seligman *et al.* 1986b
Seawater	1.6–208	San Diego Bay, Baltimore and Annapolis Harbours, USA	U.S. EPA 1975
Seawater	nd–461	California coastal waters	Stallard *et al.* 1987
Sewage treatment plant effluent	384 160-568 400	Switzerland	Mueller 1987
TRIBUTYLTIN (Bu_3Sn^+)			
Fresh water	nd–2900	Rivers and lakes in Ontario	Maguire *et al.* 1982
Fresh water	1.0–13.2	Rivers and lakes in Switzerland	Mueller 1987
Fresh water	nd–170	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
Fresh water	nd–480	Toronto Harbour, Canada	Maguire and Tkacz 1985
Fresh water	nd–5500	Across Canada	Maguire *et al.* 1986
Fresh water	4.3–13.2	Lake Zurich and Swiss rivers	Mueller 1987
Freshwater surface microlayer	nd–60 700	Rivers and lakes in Ontario, Canada	Maguire *et al.* 1982
Freshwater surface microlayer	nd–80	St. Clair River, Canada	Maguire *et al.* 1985
Freshwater surface microlayer	nd–11 352 000	Canadian rivers and lakes	Maguire and Tkacz 1987
Estuarine water	<1.0–648	U.K. harbours, anchorages	Waldock *et al.* 1988
Estuarine water	7–13.7	Coos Bay estuary, USA	Wolniakowski *et al.* 1987
Estuarine water	5–1800	N. Chesapeake Bay, USA	Hall *et al.* 1988b
Estuarine water	<2–158	Elizabeth River, Sarah Creek, Chesapeake Bay, USA	Unger *et al.* 1986
Estuarine water	nd–439	Elizabeth River, Chesapeake Bay, USA	Seligman *et al.* 1987
Estuarine water	<5–1300	Chesapeake Bay, USA	Matthias *et al.* 1986b
Estuarine water	nd–96	Sarah Creek, Chesapeake Bay, USA	Huggett *et al.* 1986
Estuarine water	nd–456	Chesapeake Bay, USA	Hall *et al.* 1986
Estuarine water	<9.8–500	Chesapeake Bay, USA	Batiuk 1987

Table B-1. Continued

Medium	Concentration[1] ($ng \cdot L^{-1}$)	Location	Reference
TRIBUTYLTIN (Bu_3Sn^+) (cont'd)			
Estuarine water	nd–1476	Various locations in England	Waldock *et al.* 1987a
Estuarine water	nd–146	Chesapeake Bay, USA	Olson and Brinckman 1986
Estuarine water	nd–91	Norfolk Harbor, USA	Pollman and Chou 1987
Estuarine water	3100	Thames estuary, U.K.	Waldock *et al.* 1987b
Estuarine water	19.7–672	Six estuaries in south and southwest England	Ebdon *et al.* 1988
Estuarine surface microlayer	nd–300	Great Bay estuary, USA	Donard *et al.* 1986
Estuarine surface microlayer	nd–4600	Baltimore Harbor, Annapolis marina, Chesapeake Bay, USA	Matthias *et al.* 1986a
Estuarine surface microlayer	nd–1200	Chesapeake Bay, USA	Hall *et al.* 1986
Seawater	168–1300	Sutton Harbour, U.K.	Waldock *et al.* 1987b
Seawater	nd–2200	Burnham-on-Crouch, U.K.	Waldock and Miller 1983
Seawater	24–144	San Diego Bay, USA	Valkirs *et al.* 1985b
Seawater	det–163	Baltimore Harbor, Annapolis marina, San Diego Bay, USA	Matthias *et al.* 1986a
Seawater	nd–816	San Diego Bay, USA	Valkirs *et al.* 1986a
Seawater	<2–6.5	Esquimalt Harbour, Canada	Kaye *et al.* 1986
Seawater	<17–336	San Diego Bay, USA	Clavell *et al.* 1986
Seawater	216–696	San Diego Bay, USA	Valkirs *et al.* 1986b
Seawater	nd–312	Various harbours in USA	Grovhoug *et al.* 1986
Seawater	2.6–206	San Diego Bay, USA	Seligman *et al.* 1986b
Seawater	<4.3–74	Annapolis and San Diego harbors, USA	Junk and Richard 1987
Seawater	4.3–295	San Diego Bay, Baltimore and Annapolis harbors, USA	Valkirs *et al.* 1987c
Seawater	528–1488	Japan	Takahashi and Ohyagi 1987
Seawater	nd–576	California coastal waters	Stallard *et al.* 1987
Sewage treatment plant effluent	288 000–6 000 000	Switzerland	Mueller 1987
Estuarine	nd–3.8	Chesapeake Bay, USA	Hall *et al.* 1986
Estuarine surface microlayer	nd–520	Chesapeake Bay, USA	Hall *et al.* 1986

Appendix C
Concentrations of Organotin Compounds Reported in Sediments

Table C-1. Concentrations of Organotin Compounds Reported in Sediments

Concentration[1] ($\mu g \cdot kg^{-1}$)	Location	Reference
MONOMETHYLTIN ($MeSn^{3+}$)		
nd–10.6 (dry weight)	Mediterranean Sea	Tugrul *et al.* 1983
nd–19 360 (dry weight)	Across Canada	Maguire *et al.* 1986
DIMETHYLTIN (Me_2Sn^{2+})		
nd–13.4 (dry weight)	Mediterranean Sea	Tugrul *et al.* 1983
nd–200 (dry weight)	Across Canada	Maguire *et al.* 1986
TRIMETHYLTIN (Me_3Sn^{3+})		
nd–19.4 (dry weight)	Mediterranean Sea	Tugrul *et al.* 1983
nd–900	Across Canada	Maguire *et al.* 1986
MONOBUTYLTIN ($BuSn^{3+}$)		
nd–7.8 (dry weight)	California coast, USA	Seidel *et al.* 1980
nd–600 (dry weight)	Rivers and lakes in Ontario, Canada	Maguire 1984
nd–51 (dry weight)	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
nd–120 (dry weight)	Toronto Harbour, Canada	Maguire and Tkacz 1985
5–29 (wet weight)	San Diego Bay, USA	Valkirs *et al.* 1985b
nd–7095 (dry weight)	Across Canada	Maguire *et al.* 1986
500–11 000 (dry weight)	Esquimalt Harbour, Canada (jetties and dry docks)	Kaye *et al.* 1986
nd–83 (dry weight)	San Diego Bay, USA	Stang and Seligman 1986
5–45 (dry weight)	Great Bay estuary, USA	Weber *et al.* 1986
nd–28.4 (dry weight)	Boston Harbor, USA	Cooney *et al.* 1988
trace (present but not quantifiable)	River Hamble, U.K.	Ashby and Craig 1989
35 (dry weight)	Lake Zurich, Switzerland (dated 1980–1984)	Mueller 1987
DIBUTYLTIN (Bu_2Sn^{2+})		
nd–350 (dry weight)	Rivers and lakes in Ontario, Canada	Maguire 1984
350 (dry weight)	Japanese river	Hattori *et al.* 1984
nd–70 (dry weight)	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
nd–1000 (dry weight)	Toronto Harbour, Canada	Maguire and Tkacz 1985
6–43 (wet weight)	San Diego Bay, USA	Valkirs *et al.* 1985b
nd–16 000 (dry weight)	Across Canada	Maguire *et al.* 1986
1–3 (wet weight)	Lake Biwa, Japan	Tsuda *et al.* 1986b
200–2700 (dry weight)	Esquimalt Harbour, Canada (jetties and dry docks)	Kaye *et al.* 1986
nd–184 (dry weight)	San Diego Bay, USA	Stang and Seligman 1986

nd = not detected

[1] Micrograms of organotin cation, except for tetraorganotins, which are not cationic.

Table C-1. Continued

Concentration[1] ($\mu g \cdot kg^{-1}$)	Location	Reference
DIBUTYLTIN (Bu_2Sn^{2+}) (cont'd)		
2–29 (dry weight)	Great Bay estuary, USA	Weber *et al.* 1986
108 (dry weight)	Lake Zurich, Switzerland (dated 1980–1984)	Mueller 1987
36–70 (dry weight)	Boston Harbor, USA	Cooney *et al.* 1988
778–3945 (dry weight)	River Hamble, U.K.	Ashby and Craig 1989
nd–1200 (dry weight)	River Beaulieu, U.K.	Ashby and Craig 1989
nd–2617 (dry weight)	River Lymington, U.K.	Ashby and Craig 1989
TRIBUTYLTIN (Bu_3Sn^+)		
nd–264 (dry weight)	San Diego Bay, USA	Stang and Seligman 1986
29–106 (dry weight)	Great Bay estuary, USA	Weber *et al.* 1986
245 (dry weight)	Lake Zurich, Switzerland (dated 1980–1984)	Mueller 1987
79–132 (dry weight)	Japanese coast	Takahashi and Ohyagi 1987
nd–528 (dry weight)	Rivers and lakes in Ontario, Canada	Maguire 1984
980[2]	Japanese river	Hattori *et al.* 1984
1.7–13.9 (dry weight)	Lakes Constance and Zurich, Switzerland	Mueller 1984
nd–177 (dry weight)	Detroit and St. Clair rivers, Canada and USA	Maguire *et al.* 1985
nd–8450 (dry weight)	Toronto Harbour, Canada	Maguire and Tkacz 1985
19–106 (wet weight)	San Diego Bay, USA	Valkirs *et al.* 1985b
nd–25 900 (dry weight)	Across Canada	Maguire *et al.* 1986
nd–2.2 (wet weight)	Lake Biwa, Japan	Tsuda *et al.* 1986b
700–17 000 (dry weight)	Esquimalt Harbour, Canada (jetties and dry docks)	Kaye *et al.* 1986
82.6–102.2 (dry weight)	Boston Harbor, USA	Cooney *et al.* 1988
451–5600 (dry weight)	River Hamble, U.K.	Ashby and Craig 1989
206–1100 (dry weight)	River Beaulieu, U.K.	Ashby and Craig 1989
276–4200 (dry weight)	River Lymington, U.K.	Ashby and Craig 1989

[2] Wet/dry weight not available.

Appendix D
Concentrations of Organotin Compounds Reported in Freshwater, Estuarine, and Marine Organisms

Table D-1. Concentrations of Organotin Compounds Reported in Freshwater, Estuarine, and Marine Organisms

Species/organism type	Concentration[1] ($\mu g \cdot kg^{-1}$)	Reference
MONOMETHYLTIN ($MeSn^{3+}$)		
Fish		
(*Upeneus moluccensis*)	27 (dry weight)	Tugrul *et al.* 1983
(*Mullus barbatus*)	0.8 (dry weight)	
Lake trout and smelt (*Salmo namaycush*) (*Osmerus mordax*)	250–990 (wet weight)	Chau *et al.* 1984
Shell samples (mollusk—species NR)	0.14–0.51[2]	Braman and Tompkins 1979
Marine algae (species NR)	nd–0.222 (wet weight)	Ishii 1982
Marine algae (species NR)	nd–0.66 (wet weight)	Ishii 1982
Seaweed (species NR)	16.8 (dry weight)	Tugrul *et al.* 1983
DIMETHYLTIN (Me_2Sn^{2+})		
Fish		
(*Upeneus moluccensis*)	2.6 (dry weight)	Tugrul *et al.* 1983
(*Mullus barbatus*)	2.9 (dry weight)	
Lake trout (*Salmo namaycush*)	225 (wet weight)	Chau *et al.* 1984
Limpet (*Patella caerulea*)	0.2–18 (dry weight)	Tugrul *et al.* 1983
Shell samples (mollusk—species NR)	nd–0.26[2]	Braman and Tompkins 1979
Marine algae (species NR)	nd–2.8 (wet weight)	Seidel *et al.* 1980
Marine algae (species NR)	nd–0.135 (wet weight)	Ishii 1982
Marine algae (species NR)	0.27–1.5 (wet weight)	Ishii 1982
Marine algae (species NR)	0.5–12 (dry weight)	Tugrul *et al.* 1983
Seaweed (species NR)	37 (dry weight)	Tugrul *et al.* 1983
TRIMETHYLTIN (Me_3Sn^{+})		
Fish		
(*Upeneus moluccensis*)	1.2 (dry weight)	Tugrul *et al.* 1983
(*Mullus barbatus*)	1.3 (dry weight)	
Limpet (*Patella caerulea*)	0.7–63 (dry weight)	Tugrul *et al.* 1983

nd = not detected

NR = not reported

[1] Micrograms of organotin cation, except for tetraorganotins, which are not cationic.

[2] Information on wet- or dry-weight basis was not available.

Table D-1. Continued

Species/organism type	Concentration[1] ($\mu g \cdot kg^{-1}$)	Reference
TRIMETHYLTIN (Me_3Sn^+) (cont'd)		
Marine algae (species NR)	nd–0.249 (wet weight)	Ishii 1982
Marine algae (species NR)	nd–5.8 (dry weight)	Tugrul *et al.* 1983
Seaweed (species NR)	0.9 (dry weight)	Tugrul *et al.* 1983
TETRAMETHYLTIN (Me_4Sn)		
Coastal marine invertebrates (species NR)	nd–8.99 (dry weight)	Seidel *et al.* 1980
Marine algae (species NR)	nd–18.8 (dry weight)	Seidel *et al.* 1980
Marine algae (species NR)	nd–9.95 (wet weight)	Ishii 1982
MONOBUTYLTIN ($BuSn^{3+}$)		
Fish (*Clupea harengus*)	nd–90 (wet weight)	Maguire *et al.* 1986
Oyster (*Crassostrea virginica*)	<8-1380 (dry weight)	Wade *et al.* 1988
Mussel (*Mytilus edulis*)	<8-1860 (dry weight)	Wade *et al.* 1988
DIBUTYLTIN (Bu_2Sn^{2+})		
Fish (*Clupea harengus*) (*Perca flavescens*) (*Catostomus commersoni*) (*Cyprinus carpio*)	nd–98 (wet weight)	Maguire *et al.* 1986
Yellowtail fish		Sasaki *et al.* 1988
white muscle	5–20 (wet weight)	
red muscle	3.9–225 (wet weight)	
liver	24.9–3700 (wet weight)	
(species NR)		
Dog whelk (*Nucella lapillus*)	41–733 (dry weight)	Gibbs *et al.* 1988
Oyster (*Crassostrea virginica*)	<10–529 (dry weight)	Wade *et al.* 1988
Mussel (*Mytilus edulis*)	<10–1700 (dry weight)	Wade *et al.* 1988
Oyster (*Ostrea sandwichensis*)	2509 (dry weight)	Wade *et al.* 1988

Table D-1. Continued

Species/organism type	Concentration^1 ($\mu g \cdot kg^{-1}$)	Reference
TRIBUTYLTIN (Bu_3Sn^+)		
Fish (*Clupea harengus*) (*Perca flavescens*) (*Catostomus commersoni*)	nd–580 (wet weight)	Maguire *et al.* 1986
(*Cyprinus carpio*)Oysters (species NR)	nd–10 800^2	Waldock and Miller 1983
Shellfish (species NR)	26^2	Tsuda *et al.* 1986b
Coho salmon (*Oncorhynchus kisutch*)	96.5–167.3 (wet weight)	Short 1987
Atlantic salmon (*Salmo salar*)	67.9 (wet weight)	Short 1987
Dog-whelk (*Nucella lapillus*)	170–187 (dry weight)	Gibbs and Bryan 1987
	86–1519 (dry weight)	Gibbs and Bryan 1986 Gibbs *et al.* 1987
	94–1774 (dry weight)	Gibbs *et al.* 1988
Oyster (*Crassostrea gigas*)	119–454 (wet weight)	Wolniakowski *et al.* 1987
Oyster (*Crassostrea gigas*)	1800 (dry weight)	Harding and Kay 1988
Oyster (*Crassostrea virginica*)	<12–1900^2	Wade *et al.* 1988
Mussel (*Mytilus edulis*)	240–3700^2	Wade *et al.* 1988
Oyster (*Ostrea sandwichensis*)	3700^2	Wade *et al.* 1988
Yellowtail fish		Sasaki *et al.* 1988
white muscle	8.9–1540 (wet weight)	
red muscle	17.7–2350 (wet weight)	
liver	29.5–1700 (wet weight)	
(species NR)		

Appendix E
Bioaccumulation of Organotin Compounds by Freshwater, Estuarine, and Marine Organisms

Table E-1. Bioaccumulation of Organotin Compounds by Freshwater, Estuarine, and Marine Organisms

Organism	Compound	Salinity $(g \cdot L^{-1})$	Water conc. $(\mu g \cdot L^{-1})$[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
VERTEBRATES							
Chinook salmon	TBTO	28	1.49	4	Liver	4300	Short and Thrower 1986a, 1986c
(*Oncorhynchus tshawytscha*)	TBTO	28	1.49	4	Brain	1300	
(adult, SW)	TBTO	28	1.49	4	Muscle	200	
Sheepshead minnow	TBTO	NR	1.6	58	Muscle	1810	Ward *et al.* 1981
(*Cyprinodon*	TBTO	NR	1.6	58	Head	2120	
variegatus)(adult, SW)	TBTO	NR	1.6	58	Viscera	4580	
	TBTO	NR	1.6	58	Whole fish	2600	
Atlantic salmon	TBT	NR	0.1	26	Caeca	900	Davies and McKie 1987
(*Salmo salar*) (SW)	TBT	NR	0.1	26	Muscle	2100	
	TBT	NR	0.1	26	Gonad	2100	
	TBT	NR	0.1	26	Gill	2400	
	TBT	NR	0.1	26	Kidney	900	
	TBT	NR	0.1	26	Liver	3900	
	TBT	NR	0.3	26	Caeca	533	Davies and McKie 1987
	TBT	NR	0.3	26	Muscle	633	
	TBT	NR	0.3	26	Gonad	1300	
	TBT	NR	0.3	26	Gill	600	
	TBT	NR	0.3	26	Kidney	900	
	TBT	NR	0.3	26	Liver	2567	
	TBT	NR	1.0	26	Caeca	240	
	TBT	NR	1.0	26	Muscle	310	
	TBT	NR	1.0	26	Gonad	390	
	TBT	NR	1.0	26	Gill	340	
	TBT	NR	1.0	26	Kidney	600	
	TBT	NR	1.0	26	Liver	1620	
Carp	MPTC	FW	6.4±1.1	14	Muscle	3.31	Tsuda *et al.* 1987b
(*Cyprinus carpio*) (FW)	MPTC	FW	6.4±1.1	14	Liver	257	
	MPTC	FW	6.4±1.1	14	Kidney	389	
	MPTC	FW	6.4±1.1	14	Gallbladder	61.7	
	DPTC	FW	2.0±0.4	14	Muscle	7.94	
	DPTC	FW	2.0±0.4	14	Liver	209	
	DPTC	FW	2.0±0.4	14	Kidney	50.1	
	DPTC	FW	2.0±0.4	14	Gallbladder	50.1	
	TPTC	FW	5.6±0.6	10	Muscle	269	
	TPTC	FW	5.6±0.6	10	Liver	912	
	TPTC	FW	5.6±0.6	10	Kidney	2089	
	TPTC	FW	5.6±0.6	10	Gallbladder	257	

TBTO = tributyltin oxide; TBT = tributyltin (anion not specified); MPTC, DPTC, TPTC = mono-, di-, and triphenyltin chlorides, respectively; DBDC = dibutyltin dichloride; DBDL = dibutyltin dilaurate; TBTC = tributyltin chloride; MBTC = monobutyltin trichloride; NR = not reported; FW = freshwater; SW = saltwater or estuarine; dw = dry weight

[1] Measured concentration of the aryl- or alkyltin cation.

[2] Bioconcentration factors (BCFs) are used synonymously with bioaccumulation factors (BAFs) and are based on measured concentrations of the organotin cation in water and in tissue (wet weight), except where noted.

Table E-1. Continued

Organism	Compound	Salinity (g•L^{-1})	Water conc. (µg•L^{-1})[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
Round crucian carp	DBDC	FW	13.2±1	7	Muscle	12	Tsuda *et al.* 1986a
(*Carassius carassius grandoculis*)	DBDC	FW	13.2±1	7	Vertebra	46	
(FW)	DBDC	FW	13.2±1	7	Liver	134	
	DBDC	FW	13.2±1	7	Kidney	60	
	TBTC	FW	6.9±0.4	7	Muscle	363	
	TBTC	FW	6.9±0.4	7	Vertebra	338	
	TBTC	FW	6.9±0.4	7	Liver	3380	
	TBTC	FW	6.9±0.4	7	Kidney	2390	
	TPTC	FW	7.5±0.5	7	Muscle	50	
	TPTC	FW	7.5±0.5	7	Vertebra	50	
	TPTC	FW	7.5±0.5	7	Liver	112	
	TPTC	FW	7.5±0.5	7	Kidney	31	
	TBTO	FW	5.4±0.3	7	Muscle	588	
	TBTO	FW	5.4±0.3	7	Vertebra	457	
	TBTO	FW	5.4±0.3	7	Liver	5010	
	TBTO	FW	5.4±0.3	7	Kidney	3160	
	DBDL	FW	10.4±1.2	7	Muscle	31	
	DBDL	FW	10.4±1.2	7	Vertebra	54	
	DBDL	FW	10.4±1.2	7	Liver	812	
	DBDL	FW	10.4±1.2	7	Kidney	138	
	TBTO	FW	2	15	Muscle	741	
	TPTC	FW	6	10	Muscle	251	
	TBTO	FW	2.1±0.2	14	Muscle	501	
	TBTO	FW	2.1±0.2	14	Liver	631	
	TBTO	FW	2.1±0.2	14	Kidney	3160	
	TBTO	FW	2.1±0.2	14	Gallbladder	1250	
	DBDC	FW	4.3±0.2	14	Muscle	0.13	
	DBDC	FW	4.3±0.2	14	Liver	10	
	DBDC	FW	4.3±0.2	14	Kidney	5	
	DBDC	FW	4.3±0.2	14	Gallbladder	8	
	MBTC	FW	6.5±0.4	14	Muscle	2	
	MBTC	FW	6.5±0.4	14	Liver	125	
	MBTC	FW	6.5±0.4	14	Kidney	50	
	MBTC	FW	6.5±0.4	14	Gallbladder	125	
Goldfish	TBTO	FW	2.0	14	Whole fish	1230	Tsuda *et al.* 1988
(*Carassius auratus*) (FW)	TPTC	FW	3.2	14	Whole fish	257	
Rainbow trout	TBTO	FW	0.51	64	Whole fish	406	Martin *et al.* 1989
(*Oncorhynchus mykiss*) (FW)	TBTO	FW	1.03	15	Liver	2869	
	TBTO	FW	1.03	15	Gallbladder	806	
	TBTO	FW	1.03	15	Kidney	5453	
	TBTO	FW	1.03	15	Carcass	3272	
	TBTO	FW	1.03	15	Peritoneal fat	13 182	
	TBTO	FW	1.03	15	Gill	2466	

Table E-1. Continued

Organism	Compound	Salinity (g·L^{-1})	Water conc. (µg·L^{-1})[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
Rainbow trout	TBTO	FW	1.03	15	Blood	1588	
(*Oncorhynchus mykiss*) (FW)	TBTO	FW	1.03	15	Gut	1185	
(cont'd)	TBTO	FW	1.03	15	Muscle	759	
INVERTEBRATES							
Mud crab	TBTO	15	5.937	6	Carapace	24	Evans and Laughlin 1984
(*Rhithropanopeus harrisii*) (SW)	TBTO	15	5.937	6	Hepatopancreas	6	
	TBTO	15	5.937	6	Testes	0.6	
	TBTO	15	5.937	6	Gill	41	
	TBTO	15	5.937	6	Chelae muscle	1.5	
Mussel (*Mytilus edulis*) (spat, SW)	TBT[3]	28.5–34.2	0.24	45	Soft parts	6833	Thain and Waldock 1985; Thain 1986
Oyster	TBTO	28–31.5	1.216	21	Soft parts	1874	Waldock *et al.* 1983
(*Crassostrea gigas*) (SW)	TBTO	28–31.5	0.1460	21	Soft parts	6047	
	TBT[3]	28.5–34.2	0.24	45	Soft parts	7292	Thain and Waldock 1985; Thain 1986
	TBTO	29–32	1.557	56	Soft parts	2300	Waldock and Thain 1983
	TBTO	29–32	0.1460	56	Soft parts	11 400	
Oyster	TBTO	28–31.5	1.216	21	Soft parts	960[4]	Waldock *et al.* 1983
(*Ostrea edulis*) (SW)	TBTO	28–34.2	0.24	75	Soft parts	875[4]	
	TBTO	28–34.2	2.62	75	Soft parts	397[4]	Thain 1986
	TBT[3]	28.5–34.2	0.24	45	Soft parts	1167[4]	Thain and Waldock 1985; Thain 1986
	TBT[3]	28.5–34.2	2.62	45	Soft parts	192[4]	
Snail (*Nucella lapillus*) (SW)	TBT	NR	Approx. 1500 as Sn in TBT	408	Soft parts	83 000 (male) (dw), 95 200 (female)	Bryan *et al.* 1987
	TBT	NR	Approx. 1500 as Sn in TBT	249	Soft parts	147 000 (male) (dw), 114 000 (female) (dw)	
	TBT	NR	3400 as Sn in TBT	249	Soft parts	112 000 (male) (dw), 89 700 (female) (dw)	
	TBT	NR	18 700 as Sn in TBT	408	Soft parts	77 900 (male) (dw), 99 700 (female) (dw)	

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[3] TBT = test organism exposure to leachate from panels coated with antifouling paint containing tributyltin.

[4] BCFs calculated based on the increase above the concentration of TBT in control organisms.

Table E-1. Continued

Organism	Compound	Salinity ($g \cdot L^{-1}$)	Water conc. ($\mu g \cdot L^{-1}$)[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
Snail (*Nucella lapillus*) (SW) (cont'd)	TBT	NR	107 000 as Sn in TBT	366	Soft parts	22 800 (male) (dw), 32 700 (female) (dw)	
	TBT	NR	0.001–0.002 as Sn in TBT	360	Soft parts	92 500–185 000 (male) (dw), 73 500–147 000 (female) (dw)	Gibbs *et al.* 1988
	TBT	NR	0.001–0.002 as Sn in TBT	540	Soft parts	95 000–190 000 (male) (dw), 125 000–250 000 (female) (dw)	
	TBT	NR	0.001–0.002 as Sn in TBT	720	Soft parts	119 000–238 000 (male) (dw), 119 500–239 000 (female) (dw)	Gibbs *et al.* 1988
	TBT	NR	0.003–0.005 as Sn in TBT	720	Soft parts	120 400–201 000 (male) (dw), 113 800–190 000 (female) (dw)	
	TBT	NR	0.02 as Sn in TBT	360	Soft parts	82 300 (male) (dw), 77 600 (female) (dw)	
	TBT	NR	0.02 as Sn in TBT	540	Soft parts	60 300 (male) (dw), 93 200 (female) (dw)	
	TBT	NR	0.02 as Sn in TBT	720	Soft parts	73 200 (male) (dw), 84 800 (female) (dw)	
	TBT	NR	0.1 as Sn in TBT	540	Soft parts	35 200 (male) (dw), 26 200 (female) (dw)	
	TBT	NR	0.1 as Sn in TBT	720	Soft parts	25 200 (male) (dw), 31 600 (female) (dw)	

Table E-1. Continued

Organism	Compound	Salinity (g·L^{-1})	Water conc. (µg·L^{-1})[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
Mussel (*Mytilus edulis*) (adult, SW)	TBTO	30±2	0.5 as TBT dissolved in water	1	Gill	973[5]	Laughlin *et al.* 1986a
					Mantle	547[5]	
					Muscle	747[5]	
					Viscera	1693[5]	
				10	Gill	2400	
					Mantle	2400	
					Muscle	2400	
					Viscera	8300	
					Whole body	4700	
	TBTO	30±2	0.5 as TBT associated with phytoplankton	1	Gill	225	
					Mantle	75	
					Muscle	75	
					Viscera	275	
				10	Gill	8300	
					Mantle	4700	
					Muscle	4700	
					Viscera	15000	
	TBTO	30±2	0.5 as TBT dissolved in water	47	Gills and viscera	6000	
					Mantle and muscle	2000	
	TBTO	30±2	0.023	14	Gill	1300[5]	Laughlin and French 1988
					Mantle	850[5]	
					Muscle	770[5]	
					Viscera	830[5]	
	TBTO	30±2	0.045	14	Gill	970[5]	
					Mantle	420[5]	
					Muscle	420[5]	
					Viscera	470[5]	
	TBTO	30±2	0.063	45	Gill	2700	
					Mantle	1400	
					Muscle	1300	
					Viscera	1600	
	TBTO	30±2	0.141	45	Gill	3900	
					Mantle	1500	
					Muscle	1600	
					Viscera	3300	

[5] Calculated steady-state bioconcentration factors.

Table E-1. Continued

Organism	Compound	Salinity ($g \cdot L^{-1}$)	Water conc. ($\mu g \cdot L^{-1}$)[1]	Exposure duration (d)	Tissue	BCF or BAF[2]	Reference
Mussel (*Mytilus edulis*) (adult, SW) (cont'd)	TBTO	30±2	0.670	45	Gill	7300	
					Mantle	2200	
					Muscle	1900	
					Viscera	3100	
Clam (*Anodonta anatina*) (adult, FW)	DBDC	FW	38 ($15\ \mu g\ Sn \cdot L^{-1}$)	210	Gill	63	Holwerda and Herwig 1986
					Mantle	9	
					Foot	15	
					Midgut gland	40	
					Kidney	1570	
ALGAE							
Green alga[6] (*Ankistrodesmus falcatus*) (FW)	TBTO		5.2	7		300	Maguire *et al.* 1984
	TBTO		4.7	17		253	
	TBTO		2.1	21		448	
	TBTO		1.5	28		467	
AQUATIC VASCULAR PLANTS							
Eelgrass (*Zostera marina*) (SW)	TBT	14	0.067	14	Shoot	12 000	François *et al.* 1989

[6] Algae grown in Chu-10 medium.

Appendix F
Summary of Acute and Chronic Organotin Toxicity Data for Freshwater, Estuarine, and Marine Vertebrates

Table F-1. Summary of Acute and Chronic Organotin Toxicity Data for Freshwater Vertebrates

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Rainbow trout (*Oncorhynchus mykiss*)	Bis(tributyltin) oxide	24 h 48 h	LC_{50}=0.028 mg•L^{-1} LC_{50}=0.021 mg•L^{-1}	UN	95% soln; Hard=250 mg•L^{-1}; static renewal test; conc not measured	Alabaster 1969
	Triphenyltin hydroxide	24 h 48 h 96 h	LC_{50}=0.074 mg•L^{-1} LC_{50}=0.029 mg•L^{-1} LC_{50}=0.014 mg•L^{-1}	SE	Flow-through test; conc not measured; Hard=270 mg•L^{-1}; 15°C	Tooby *et al.* 1975
Guppy (*Poecilia reticulata*)	Bis(tributyltin) oxide	24 h	LC_{100}=0.075 mg•L^{-1}	UN	Resistant to 0.03 mg•L^{-1}; observations of mortality for 48 h after end of exposure	Floch *et al.* 1964
	Bis(tributyltin) oxide	24 h	LC_{50}=0.01–0.02 mg•L^{-1}	UN		Schatzberg and Harris 1978
	Triphenyltin acetate	24 h	LC_{50}=0.12 mg•L^{-1}	UN	25°C; other conditions unknown	Knauf 1974
		48 h	LC_{50}=0.054 mg•L^{-1}	UN	25°C; other conditions unknown	
		24 h	LC_{100}=0.075 mg•L^{-1}	UN	Resistant to 0.02 mg•L^{-1}; observations of mortality for 48 h after end of exposure	Floch *et al.* 1964
		48 h	LC_{100}=0.03 mg•L^{-1}			
Fathead minnow (*Pimephales promelas*)	Bis(tributyltin) oxide	96 h	LC_{50}=0.05–0.2 mg•L^{-1}	UN	Raw and treated wastewater; static test; conc not measured	Argaman *et al.* 1984
Mosquitofish (*Gambusia affinis*)	Triphenyltin acetate	24 h	LC_{100}=0.4 mg•L^{-1}	SE	Static test; conc not measured; pH=6.8	Gras and Rioux 1965
Eel (*Anguilla anguilla*)	Triphenyltin acetate	24 h	LC_{100}=0.86 mg•L^{-1}	SE	Static test; conc not measured; pH=6.8	Gras and Rioux 1965
Goldfish (*Carassius auratus*)	Triphenyltin acetate	24 h	LC_{100}=0.34 mg•L^{-1}	SE	Static test; conc not measured; pH=6.8	Gras and Rioux 1965
	Triphenyltin acetate	24 h	LC_{100}=0.075 mg•L^{-1}	UN	Resistant to 0.03 mg•L^{-1}; observations of mortality for 48 h after end of exposure	Floch *et al.* 1964
	Triphenyltin chloride	24 h 48 h	LC_{100}=0.25 mg•L^{-1} LC_{100}=0.25 mg•L^{-1}	UN	Conditions NR	Floch and Deschiens 1962

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[1] Unless otherwise indicated, all concentrations reported for primary and secondary studies are the concentration of the organotin cation. Tests with compounds that contained less than 95% organotin active ingredient were corrected accordingly (95% confidence limits in parentheses). Data from unacceptable studies are as published.

wt = weight
conc = concentration
NR = not reported
soln = solution
Hard = hardness as mg•L^{-1} $CaCO_3$
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian water quality interim guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table F-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Goldfish (*Carassius auratus*) (cont'd)	Triphenyltin oxide	24 h	LC_{100}=0.075 mg•L^{-1}	UN	Resistant to 0.03 mg•L^{-1}; observations of mortality for 48 h after end of exposure	Floch *et al.* 1964
Carp (*Cyprinus carpio*)	Triphenyltin acetate	24 h	LC_{50}=0.521 mg•L^{-1}	UN	Conditions unknown; unpublished data	Ueda *et al.* 1961
		48 h	LC_{50}=0.32 mg•L^{-1}			
		24 h	LC_{50}=1.2 mg•L^{-1}	UN	Conditions unknown; unpublished data	Knauf 1974
		48 h	LC_{50}=0.84 mg•L^{-1}			
Sunfish (species unknown)	Triphenyltin acetate	48 h	LC_{100}=1 mg•L^{-1}	UN	Study conducted in pond; conditions NR	Seiffer and Schoof 1967
Freshwater teleost (*Idus idus melanotus*)	Triphenyltin acetate	24 h	LC_{50}=0.18 mg•L^{-1}	UN	22°C; other conditions unknown	Knauf 1974
		48 h	LC_{50}=0.11 mg•L^{-1}	UN	22°C; other conditions unknown	
Harlequin fish (*Rasbora heteromorpha*)	Triphenyltin acetate (20% soln)	24 h	LC_{50}=0.084 mg•L^{-1}	UN	Hard=20 mg•L^{-1}; 20°C; flow-through test	Alabaster 1969
		48 h	LC_{50}=0.044 mg•L^{-1}		Conc not measured; 20% soln (Lirostanol)	
	Triphenyltin hydroxide (100% soln)	24 h	LC_{50}=0.059 mg•L^{-1}	SE	Flow-through test; conc not measured; Hard=20 mg•L^{-1}; 20°C	Tooby *et al.* 1975
	Triphenyltin hydroxide (20% soln)	24 h	LC_{50}=0.072 mg•L^{-1}			
		48 h	LC_{50}=0.046 mg•L^{-1}			
		96 h	LC_{50}=0.014 mg•L^{-1}			
Stickleback (spawn) (species unknown)	Triphenyltin chloride	24 h	LC_{100}=0.25 mg•L^{-1}	UN	Conditions NR	Floch and Deschiens 1962
		48 h	LC_{100}=0.25 mg•L^{-1}	UN	Conditions NR	
Bluegill (*Lepomis macrochirus*)	Triphenyltin hydroxide	48 h	LC_{50}=0.033 mg•L^{-1}	UN		FAO 1969
	Tricyclohexyltin hydroxide	96 h	LC_{50}=6.7 µg•L^{-1} (5.8–7.7 µg•L^{-1})	UN	18°C; Hard=40–50 mg•L^{-1}	Johnson and Finley 1980
Largemouth bass (*Micropterus salmoides*)	Tricyclohexyltin hydroxide	24 h	LC_{50}=0.06 mg•L^{-1}	UN		Dow Chemical Co. 1979
		96 h	LC_{50}=2.1 µg•L^{-1} (1.9–2.3 µg•L^{-1})	UN	18°C; Hard=272 mg•L^{-1}	Johnson and Finley 1980
Channel catfish (*Ictalurus punctatus*)	Bis(tributyltin) oxide	96 h	LC_{50}=0.012 mg•L^{-1}	UN	Conditions unknown; unpublished data	Slesinger 1979

Table F-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Jewel fish (*Tilapia nilotica*)	Bis(tributyltin) oxide	24–48 h	LC_{70}=0.044 mg•L^{-1}	SE	No mortality at 0.015–0.03 mg•L^{-1} after 15 d	Deschiens *et al.* 1966
Golden orfe (*Leuciscus idus melanotus*)	Bis(tributyltin) oxide	48 h	LC_{50}=0.05 mg•L^{-1}	UN	Conditions NR	Plum 1981
Goldfish (*Carassius auratus*)	Triphenyltin acetate	24 h	LC_{50}=0.578 mg•L^{-1}	SE	pH=7.4; Hard=307 mg•L^{-1}; static test; conc not measured	Cotta-Ramusino and Doci 1987
		48 h	LC_{50}=0.53 mg•L^{-1}	SE	pH=7.4; Hard=307 mg•L^{-1}; static test; conc not measured	
Rainbow trout (*Oncorhynchus mykiss*)	Triphenyltin hydroxide	24 h	LC_{50}=100 µg•L^{-1}	UN	pH=7.1; Hard=44 mg•L^{-1}; 13°C; static test; conc measured	Mayer and Ellersieck 1986
	Triphenyltin hydroxide	96 h	LC_{50}<28 µg•L^{-1}	UN	pH=7.1; Hard=44 mg•L^{-1}; 13°C; static test; conc measured	
Goldfish (*Carassius auratus*)	Triphenyltin hydroxide	24 h	LC_{50}=121 µg•L^{-1} (99–149)	UN	As above except 18°C	Mayer and Ellersieck 1986
	Triphenyltin hydroxide	96 h	LC_{50}=62 µg•L^{-1} (49–75)	UN	As above except 18°C	
Fathead minnow (*Pimephales promelas*)	Triphenyltin hydroxide	24 h	LC_{50}=76 µg•L^{-1} (58–100)	UN	As above except 18°C	Mayer and Ellersieck 1986
	Triphenyltin hydroxide	96 h	LC_{50}=20 µg•L^{-1} (9.0–42)	UN	As above except 18°C	
Bluegill (*Lepomis macrochirus*)	Triphenyltin hydroxide	24 h	LC_{50}=76 µg•L^{-1}	UN	As above except 24°C	Mayer and Ellersieck 1986
	Triphenyltin hydroxide	96 h	LC_{50}=23 µg•L^{-1} (19–28)	UN	As above except 24°C	
Rainbow trout (*Oncorhynchus mykiss*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=3.9 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=50.6 mg•L^{-1}	Brooke *et al.* 1986
Rainbow trout (*Oncorhynchus mykiss*) (mean wt = 1.5 g)	Bis(tributyltin) oxide	96 h	LC_{50}=3.63 µg•L^{-1} LC_{50}=3.12 µg•L^{-1} LC_{50}=3.56 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=135 mg•L^{-1}; 15.5°C; pH=7.76	Martin *et al.* 1989
Lake trout (*Salvelinus namaycush*) (mean wt = 5.94 g)	Bis(tributyltin) oxide	96 h	LC_{50}=12.7 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=135 mg•L^{-1}; 15.5°C; pH=7.76	Martin *et al.* 1989

Table F-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Fathead minnow (*Pimephales promelas*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=2.6 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=50.6 mg•L^{-1}	Brooke *et al.* 1986
Channel catfish (*Ictalurus punctatus*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=5.5 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=50.6 mg•L^{-1}	Brooke *et al.* 1986
Bluegill (*Lepomis macrochirus*)	Bis(tributyltin) oxide	96 h	LC_{50}=240 µg•L^{-1}	UN	Static test; conc not measured	Foster 1981
Fathead minnow (*Pimephales promelas*) (larvae)	Triphenyltin hydroxide	96 h	LC_{50}=6.8 µg•L^{-1}	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1}	Jarvinen *et al.* 1988
		96 h	EC_{50}=3.5 µg•L^{-1} Change in behaviour	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1}	
		12 h	96-h LC_{50}=58.9 µg•L^{-1}	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		12 h	96-h EC_{50}=48.0 µg•L^{-1} (41.2–55.9) Change in behaviour	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		24 h	96-h LC_{50}=19.1 µg•L^{-1} (16.3–22.2)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
	Triphenyltin hydroxide	24 h	96-h EC_{50}=15.1 µg•L^{-1} (12.7–17.9) Change in behaviour	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	Jarvinen *et al.* 1988
		48 h	96-h LC_{50}=6.2 µg•L^{-1} (5.7–6.8)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96 h test period)	
		48 h	96-h EC_{50}=4.77 µg•L^{-1} (4.1–5.4) Change in behaviour	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		72 h	96-h LC_{50}=5.72 µg•L^{-1} (4.9–6.8)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		72 h	96-h EC_{50}=3.34 µg•L^{-1} Change in behaviour	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	

Table F-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Fathead minnow (*Pimephales promelas*) (larvae) (cont'd)		24 h	30-d LC_{50}=15.6 µg•L^{-1} (13.9–17.6)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		48 h	30-d LC_{50}=8.20 µg•L^{-1}	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
		72 h	30-d LC_{50}=3.72 µg•L^{-1} (3.3–4.2)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1} (partial exposure for 96-h test period)	
Frog (*Rana temporaria*) (embryo, larva)	Bis(tributyltin) oxide	5 d	LC_{40}=28.4 µg•L^{-1}	UN	Static test; conc not measured	Laughlin and Linden 1982
	Tributyltin fluoride	5 d	LC_{50}=28.2 µg•L^{-1}			
Guppy (*Poecilia reticulata*)	Bis(tributyltin) oxide	7 d	LC_{50}=0.039 mg•L^{-1}	UN	Conditions NR	Polster and Halacka 1971
	Triphenyltin acetate	7 d	LC_{50}=0.032 mg•L^{-1}	UN	Conditions NR	
	Tributyltin chloride	7 d	LC_{50}=0.021 mg•L^{-1}	UN	Conditions NR	
	Tributyltin oleate	7 d	LC_{50}=0.033 mg•L^{-1}	UN	Conditions NR	
	Tributyltin benzoate	7 d	LC_{50}=0.025 mg•L^{-1}	UN	Conditions NR	
	Tributyltin laurate	7 d	LC_{50}=0.030 mg•L^{-1}	UN	Conditions NR	
	Tributyltin acetate	7 d	LC_{50}=0.028 mg•L^{-1}	UN	Conditions NR	
Rainbow trout (*Oncorhynchus mykiss*) (yolk sac fry)	Tributyltin chloride	12 d	LC_{100}=4.9 µg•L^{-1}	SE	Flow-through test; conc not measured;	Seinen *et al.* 1981
		110 d	0.19 µg•L^{-1} caused diminished glycogen storage; retarded growth; weight decrease	SE	Hard=94–102 mg•L^{-1}; 15°C	
Fathead minnow (*Pimephales promelas*) (larvae)	Triphenyltin hydroxide	30 d	LC_{50}=1.43 µg•L^{-1} (1.4-1.6) LOEL=0.22 µg•L^{-1} (growth)	PR	Static test; conc measured; 24.2°C–25.3°C; Hard=46.6 mg•L^{-1}	Jarvinen *et al.* 1988
Fathead minnow (*Pimephales promelas*) (juvenile)	Bis(tributyltin) oxide	33 d post fertilization	0.08 µg•L^{-1} caused significant reduction in mean standard length at 28 d post-hatch	PR	Flow-through test; conc measured; Hard=50.6 mg•L^{-1}	Brooke *et al.* 1986

Table F-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Guppy (*Poecilia reticulata*)	Bis(tributyltin) oxide	90 d	LOEL = 0.97 μg•L^{-1} for growth	PR	pH=7.8–8.3; 21°C–25°C; static renewal test; conc measured	Wester and Canton 1987
		90 d	LOEL = 0.031 μg•L^{-1} for histopathological changes			
Guppy (*Poecilia reticulata*) (cont'd)	Dibutyltin	30 d	NOEL = 1.44 mg•L^{-1} for mortality and behaviour	PR	pH=7.8–8.3; 21°C–25°C; static renewal test; conc measured	
		30 d	LOEL = 245 μg•L^{-1} for histopathological changes			

Table F-2. Summary of Acute and Chronic Organotin Toxicity Data for Estuarine and Marine Vertebrates

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Mummichog (*Fundulus heteroclitus*)	Bis(tributyltin) oxide	40 min	Significant avoidance of 3.7 µg Sn•L^{-1}	PR	Flow-through test; conc measured; 22–27.5°C; Sal = 9.9–11.2 g•L^{-1}	Pinkney *et al.* 1985
Sheepshead minnow (*Cyprinodon variegatus*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=16.54 µg•L^{-1}	UN	Sal = 20 g•L^{-1}; static test; conc not measured	EG&G Bionomics 1979
		96 h	LC_{50}=12.65 µg•L^{-1}	UN	Sal = 20 g•L^{-1}; static test; conc not measured	
Sheepshead minnow (*Cyprinodon variegatus*) (33-49 mm)	Bis(tributyltin) oxide	96 h	LC_{50}=2.315 µg•L^{-1}	UN	Sal = 28–32 g•L^{-1}; flow-through test; conc measured	EG&G Bionomics 1981b
Mummichog (*Fundulus heteroclitus*) (adult)	Bis(tributyltin) oxide	96 h	LC_{50}=23.36 µg•L^{-1}	UN	Sal = 25 g•L^{-1}; static test; conc not measured	EG&G Bionomics 1976
Bleak (*Alburnus alburnus*)	Triphenyltin fluoride	96 h	LC_{50}=0.32–0.44 µg•L^{-1}	SE	Static test; conc not measured; 10°C; pH=7.8; Sal = 7 g•L^{-1}	Linden *et al.* 1979
	Tributyltin fluoride	96 h	LC_{50}=5.6–7.5 µg•L^{-1}	SE	Static test; conc not measured; 10°C; pH=7.8; Sal = 7 g•L^{-1}	
	Bis(tributyltin) oxide	96 h	LC_{50}=12.6–16.5 µg•L^{-1}	SE	Static test; conc not measured; 10°C; pH=7.8; Sal = 7 g•L^{-1}	Linden *et al.* 1979
North Sea sole (*Solea solea*) (adult)	Bis(tributyltin) oxide	48 h 96 h	LC_{50}=0.088 mg•L^{-1} LC_{50}=0.036 mg•L^{-1}	UN UN	Static renewal test; other conditions NR	Thain 1983
North Sea sole (*Solea solea*) (larvae)	Bis(tributyltin) oxide	48 h 96 h	LC_{50}=0.0085 mg•L^{-1} LC_{50}=0.0021 mg•L^{-1}	UN UN	Static renewal test; other conditions NR	Thain 1983
Teleost (*Agonus cataphactus*)	Bis(tributyltin) oxide	48 h 96 h	LC_{50}=0.026 mg•L^{-1} LC_{50}=0.016 mg•L^{-1}	UN UN	Static renewal test; other conditions NR	Thain 1983
Chinook salmon (*Oncorhynchus tshawytscha*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=1.46 µg•L^{-1}	SE	Sal=28 g•L^{-1}; static test; conc measured	Short and Thrower 1986b
Speckled sanddab (*Chithorichthys stigmaeus*)	Bis(tributyltin) oxide	96 h	LC_{50}=18.5 µg•L^{-1}	UN	Sal=33-34 g•L^{-1}	Salazar and Salazar (undated)

[1] Unless otherwise indicated, all concentrations reported for primary and secondary studies are the concentration of the organotin cation. Data from unacceptable studies are as published.

conc = concentration
NR = not reported
Sal = Salinity
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian water quality interim guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table F-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Chinook salmon (*Oncorhynchus tshawytscha*)	Bis(tributyltin) oxide	6 h 12 h	LC_{50}=52.6 μg•L^{-1} LC_{50}=19.5 μg•L^{-1}	SE	Static test; 3°C–5°C; Sal=28 g•L^{-1}; conc measured	Short and Thrower 1987
		96 h	LC_{50}=1.46 μg•L^{-1}	SE	Static test; 3°C–5°C; Sal=28 g•L^{-1}; conc measured	Short and Thrower 1987
Sheepshead minnow (*Cyprinodon variegatus*)	Bis(tributyltin) oxide	7 d	LC_{50}=1.75 μg•L^{-1}	SE	Flow-through test; conc measured; TBT conc varied during test	Ward *et al.* 1981
		14 d	LC_{50}=0.97 μg•L^{-1}	SE	Flow-through test; conc measured; TBT conc varied during test	
		21 d	LC_{50}=0.93 μg•L^{-1}	SE	Flow-through test; conc measured; TBT conc varied during test	
California grunion (*Leuresthes tenuis*) (egg through embryo)	Tributyltin	10 d	50% reduction in hatching success at 74 μg•L^{-1}; no adverse effect on hatching success or growth at 0.14–1.72 μg•L^{-1}	SE	Flow-through test; conc measured; TBT exposure from painted panels	Newton *et al.* 1985
Atlantic menhaden (*Brevoortia tyrannus*) (juvenile)	Tributyltin chloride	28 d	Survival not affected by 93 or 490 ng•L^{-1}; no definitive histological changes	PR	Flow-through test; conc measured; 20°C; Sal=10–11 g•L^{-1}	Hall *et al* 1988c
Inland silverside (*Menidia beryllina*) (larvae)	Tributyltin chloride	28 d	Survival not affected by 93 or 490 ng•L^{-1}; both conc significantly reduced growth by 20%–22%	PR	Flow-through test; conc measured; 20°C; Sal=10–11 g•L^{-1}	Hall *et al* 1988c
Flatfish (*Citharichthys stigmaeus*)	Tributyltin	66 d	LC_{50}=1.89–2.80 μg•L^{-1}	UN	Flow-through test; conc measured; 17°C; TBT exposure from printed panels; control mortality was 47%	Valkirs *et al* 1985a

Appendix G

Summary of Acute and Chronic Organotin Toxicity Data for Freshwater, Estuarine, and Marine Invertebrates

Table G-1. Summary of Acute and Chronic Organotin Toxicity Data for Freshwater Invertebrates

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Snail (*Biomphalaria glabrata*) (adult)	Tripropyltin oxide	24 h	LC_{50}=0.085 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964: Ritchie *et al.* 1964
	Tripropyltin oxide	24 h	LC_{90}=0.115 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tripropyltin oxide	6 h	LC_{50}=0.78 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tripropyltin oxide	6 h	LC_{90}=1.05 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tripropyltin oxide	6 h	LC_{50}=0.65 mg•L^{-1}	UN	25°C; other conditions NR	Seiffer and Schoof 1967
	Tripropyltin oxide	6 h	LC_{95}=1.7 mg•L^{-1}	UN	Static test; other conditions NR	Seiffer and Schoof 1967
	Tripropyltin oxide	NR	LC_{50}=0.28 mg•L^{-1}	UN	Conditions unknown; unpublished data	Paulini 1964
	Tripropyltin oxide	24 h	LC_{50}=0.05-0.1 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tripropyltin pentachlorophenate	24 h	LC_{50}=0.1-0.5 mg•L^{-1}	UN		
	Tributyltin acetate	24 h	LC_{50}=0.085 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tributyltin acetate	24 h	LC_{90}=0.115 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tributyltin acetate	6 h	LC_{50}=0.19 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tributyltin acetate	6 h	LC_{90}=0.3 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964; Ritchie *et al.* 1964
	Tributyltin acetate	24 h	LC_{100}=0.30 mg•L^{-1}	UN	Conditions NR	Floch *et al.* 1964

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[1] Unless otherwise indicated, all concentrations reported for primary and secondary studies are the concentration of the organotin cation. Tests with compounds that contained less than 95% organotin active ingredient were corrected accordingly. Data from unacceptable studies are as published.

Hard = hardness as mg•$L^{-1}CaCO_3$
soln = solution
conc = concentration
NR = not reported
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian interim water quality guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Snail (*Biomphalaria glabrata*) (adult) (cont'd)			LC_{50}=0.17 mg•L^{-1}	UN	Conditions unknown; unpublished data	Paulini 1964
	Tributyltin acetate	24 h	LC_{50}=0.1-0.3 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tributyltin pentachlorophenate	24 h	LC_{50}=0.05-0.1 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Bis(tributyltin) oxide	24 h	LC_{100}=0.075 mg•L^{-1}	UN	Conditions NR	Floch *et al.* 1964; Deschiens and Floch 1968
	Bis(tributyltin) oxide	24 h	LC_{50}=0.029 mg•L^{-1}	SE		Deschiens *et al.* 1966
	Bis(tributyltin) oxide	24 h	LC_{50}=0.05–0.1 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Bis(tributyltin) oxide	6 h	LC_{50}=0.41 mg•L^{-1}	UN	Static test; other conditions NR	Seiffer and Schoof 1967
	Bis(tributyltin) oxide	6 h	LC_{95}=0.84 mg•L^{-1}	UN	Static test; other conditions NR	Seiffer and Schoof 1967
	Bis(tributyltin) oxide	24 h	LC_{50}=0.04 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Bis(tributyltin) oxide	24 h	LC_{90}=0.105 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Bis(tributyltin) oxide	6 h	LC_{50}=0.37 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Bis(tributyltin) oxide	6 h	LC_{90}=0.9 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Bis(tributyltin) oxide	Continuous	10 µg•L^{-1} inhibited oviposition by 100%; 1 µg•L^{-1} inhibited oviposition by >90%	UN	Conc not measured	Ritchie *et al.* 1974
	Bis(tributyltin) oxide	Continuous	0.1 µg•L^{-1} inhibited oviposition by 50%	UN	Conc not measured	Ritchie *et al.* 1974
	Bis(tributyltin) oxide	Continuous	10 µg•L^{-1} prohibited development of newly laid eggs; 0.001 µg•L^{-1} significantly reduced survival of snails after hatching; 1 and 0.1 µg•L^{-1} severely retarded growth	UN	Conc not measured	Ritchie *et al.* 1974

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Snail (*Biomphalaria glabrata*) (adult) (cont'd)	Triphenyltin acetate	24 h	LC$_{50}$=0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf and Muller 1962; Hopf *et al.* 1967
	Triphenyltin acetate	24 h	LC$_{100}$=1.0 mg•L^{-1}	UN	Conditions NR	Deschiens and Floch 1962; Floch and Deschiens 1962
	Triphenyltin acetate	48 h	LC$_{100}$=0.25 mg•L^{-1}	UN	Conditions NR	Deschiens and Floch 1962
	Triphenyltin acetate	24 h	LC$_{50}$=0.66 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964
	Triphenyltin acetate	24 h	LC$_{90}$=1.55 mg•L^{-1}	UN	25°C; other conditions NR	Frick and de Jimenez 1964
	Triphenyltin acetate	NR	LC$_{50}$=0.26 mg•L^{-1}	UN	Conditions unknown; unpublished data	Paulini 1964
	Triphenyltin acetate	NR	LC$_{50}$=0.50 mg•L^{-1}	UN	Conditions unknown; unpublished data	Paulini 1964
	Triphenyltin acetate	6 h	LC$_{50}$=0.4 mg•L^{-1}	UN	20% soln; static test; other conditions NR	Seiffer and Schoof 1967
	Triphenyltin acetate	6 h	LC$_{95}$=1.4 mg•L^{-1}	UN	20% soln; static test; other conditions NR	Seiffer and Schoof 1967
	Triphenyltin chloride	24 h	LC$_{100}$=1.00 mg•L^{-1}	UN	Conditions NR	Floch and Deschiens 1962; Deschiens and Floch 1962
	Triphenyltin chloride	48 h	LC$_{100}$=0.25 mg•L^{-1}	UN	Conditions NR	Floch and Deschiens 1962; Deschiens and Floch 1962
	Triphenyltin chloride	6 h	LC$_{50}$=5.5 mg•L^{-1}	UN	Static test; other conditions NR	Seiffer and Schoof 1967
	Triphenyltin chloride	6 h	LC$_{95}$=19.0 mg•L^{-1}	UN	Static test; other conditions NR	Seiffer and Schoof 1967
	Triphenyltin fluoride	24 h	LC$_{50}$=0.01–0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Triphenyltin pentachlorophenate	24 h	LC$_{50}$=0.1–1.0 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tris-p-chlorphenyltin acetate	24 h	LC$_{50}$=0.01–0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tris(2-phenylethyl)tin acetate	24 h	LC$_{50}$=0.01–0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tribenzyltin pentalorophenate	24 h	LC$_{50}$=1.0 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Snail (*Biomphalaria glabrata*) (adult) (cont'd)	Tri(cyclopentyl-methyl)tin acetate	24 h	LC_{50}=0.05–0.1 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tricyclopentyltin acetate	24 h	LC_{50}=0.05–0.1 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tri-m-tolyltin acetate	24 h	LC_{50}=0.01–0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
	Tri-p-tolyltin acetate	24 h	LC_{50}=0.01–0.05 mg•L^{-1}	UN	Static test; conc not measured; observations of mortality for 24 h after end of exposure	Hopf *et al.* 1967
Snail (*Biomphalaria sudanica*)	Triphenyltin acetate	NR	LC_{50}=0.04 mg•L^{-1}	UN	Conditions unknown; unpublished data	Webbe 1963
	Tributyltin acetate	NR	LC_{50}=0.03 mg•L^{-1}	UN	Conditions unknown; unpublished data	Webbe 1963
Snail (*Biomphalaria contortus*)	Triphenyltin acetate	24 h	LC_{100}=0.30 mg•L^{-1}	UN	Conditions NR	Floch *et al.* 1964
	Bis(tributyltin) oxide	24 h	LC_{100}=0.075 mg•L^{-1}	UN	Conditions NR	Floch *et al.* 1964; Deschiens and Floch 1968
	Bis(tributyltin) oxide	24 h	LC_{50}=0.029 mg•L^{-1}	SE	Field study; static water; conc not measured	Deschiens *et al.* 1966
	Triphenyltin acetate	24 h	LC_{100}=1.00 mg•L^{-1}	UN	Conditions NR	Deschiens and Floch 1962 Floch and Deschiens 1962
	Triphenyltin acetate	48 h	LC_{100}=0.25 mg•L^{-1}	UN	Conditions NR	Deschiens and Floch 1962
	Triphenyltin chloride	24 h	LC_{100}=1.00 mg•L^{-1}	UN	Conditions NR	Floch and Deschiens 1962
	Triphenyltin chloride	48 h	LC_{100}=0.25 mg•L^{-1}	UN	Conditions NR	Deschiens and Floch 1962
Snail (*Biomphalaria tropicus*)	Triphenyltin acetate	NR	LC_{50}=0.075 mg•L^{-1}	UN	Conditions unknown; unpublished data	de Villiers and MacKenzie 1963
	Triphenyltin hydroxide	NR	LC_{50}=0.05 mg•L^{-1}	UN	Conditions unknown; unpublished data	de Villiers and MacKenzie 1963
	Triphenyltin hydroxide	24 h	LC_{50}=0.165 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Triphenyltin hydroxide	24 h	LC_{90}=0.232 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Triphenyltin hydroxide	24 h	LC_{50}=0.335 mg•L-1	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Triphenyltin hydroxide	24 h	LC_{90}=0.53 mg•L^{-1}	UN	25°C; other conditions NR	Ritchie *et al.* 1964
	Bis(tributyltin) oxide	NR	LC_{50}=0.01 mg•L^{-1}	UN	Conditions unknown; unpublished data	de Villiers and Mackenzie 1963

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Snail (*Biomphalaria nasutus*)	Triphenyltin acetate	NR	LC_{50}=0.03 mg•L^{-1}	UN	Conditions unknown; unpublished data	Webbe 1963
	Tributyltin acetate	NR	LC_{50}=0.03 mg•L^{-1}	UN	Conditions unknown; unpublished data	Webbe 1963
Hydra (*Hydra* sp.)	Bis(tributyltin) oxide	96 h	EC_{50}=0.5 µg•L^{-1} (shortened tentacles)	PR	Static test; conc measured; Hard=50.5–51.5 mg•L^{-1}; pH=7.48–7.60; 24.1°C–27.4°C	Brooke *et al.* 1986
Annelid (*Lumbriculus variegatus*)	Bis(tributyltin) oxide	96 h	EC_{50}=5.4 µg•L^{-1} (immobile)	PR	Flow-through test; conc measured; Hard=50.8–53.1 mg•L^{-1}; pH=7.07–7.11; 16.7°C–19.2°C	Brooke *et al.* 1986
Copepod (*Daphnia magna*) (< 24 h old)	Bis(tributyltin) oxide	48 h	EC_{50}=4.3 µg•L^{-1} (immobile)	PR	Flow-through test; conc measured; Hard=50.7–52.1 mg•L^{-1}; pH=7.46–7.57; 22.4°C–25.9°C	Brooke *et al.* 1986
Amphipod (*Gammarus pseudolimnaeus*)	Bis(tributyltin) oxide	96 h	LC_{50}=3.7 µg•L^{-1}	PR	Flow-through test; conc measured; Hard=50.8–53.1 mg•L^{-1}; pH=7.07–7.11; 16.7°C–19.2°C	Brooke *et al.* 1986
Mosquito (*Culex* sp.) (larva)	Bis(tributyltin) oxide	96 h	EC_{50}=10.2 µg•L^{-1} (immobile)	PR	Static test; conc measured; Hard=50.0–56.0 mg•L^{-1}; pH=7.52–7.59; 16.5°C–17.2°C	Brooke *et al.* 1986
Copepod (*Daphnia magna*)	Bis(tributyltin) oxide	48 h	EC_{50}=70 µg•L^{-1}	UN	Static test; conc not measured	Foster 1981
		96 h	LC_{50}=66.3 µg•L^{-1}			
Copepod (*Daphnia magna*)	Tributyltin chloride	96 h	LC_{50}=5.26 µg•L^{-1}	UN	Static test; conc not measured	Meador 1986
Asiatic clam (*Corbicula fluminea*) (larvae)	Bis(tributyltin) oxide	24 h	EC_{50}=2.1 mg•L^{-1}	UN	Static test; conc not measured	Foster 1981
Copepod (*Daphnia magna*) (<24 h old)	Monomethyltin trichloride	24 h	IC_{50}=50.2 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Monobutyltin trichloride	24 h	IC_{50}=30.4 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Dimethyltin dichloride	24 h	IC_{50}=65.4 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Diethyltin dichloride	24 h	IC_{50}=2.78 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Copepod (*Daphnia magna*) (<24 h old) (cont'd)	Dibutyltin dichloride	24 h	IC_{50}=0.69 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Diphenyltin dichloride	24 h	IC_{50}=0.52 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Trimethyltin chloride	24 h	IC_{50}=0.39 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Triethyltin bromide	24 h	IC_{50}=0.19 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Tripropyltin chloride	24 h	IC_{50}=0.032 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Tributyltin chloride	24 h	IC_{50}=0.012 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Bis(tributyltin) oxide	24 h	IC_{50}=0.014 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Triphenyltin chloride	24 h	IC_{50}=0.017 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Tetramethyltin	24 h	IC_{50}=40 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Tetrapropyltin	24 h	IC_{50}=1.18 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
	Tetrabutyltin	24 h	IC_{50}=1.55 mg•L^{-1}	SE	pH=7.5; Hard=200 mg•L^{-1}; 20°C; static test; conc not measured	Vighi and Calamari 1985
Amphipod (*Gammarus fasciatus*)	Triphenyltin hydroxide	24 h	LC_{50}=2600 µg•L^{-1} (1870-3620)	UN	pH=7.1; Hard=44 mg•L^{-1}; 12°C; static test; conc measured	Mayer and Ellersieck 1986
	Triphenyltin hydroxide	96 h	LC_{50}=66 µg•L^{-1} (42–103)	UN	pH=7.1; Hard=44 mg•L^{-1}; 12°C; static test; conc measured	Mayer and Ellersieck 1986
Isopod (*Asellus aquaticus*)	Triphenyltin acetate (60% of Brestan)	24 h 48 h	LC_{50}=2.1 mg•L^{-1} LC_{50}=0.66 mg•L^{-1}	SE	pH=7.4; Hard=307 mg•L^{-1}; static test; conc not measured	Cotta-Ramusino and Doci 1987
Midge (*Chironomus riparius*) (larvae)	Triphenyltin acetate (60% of Brestan)	24 h 48 h	LC_{50}=0.042 mg•L^{-1} LC_{50}=0.03 mg•L^{-1}	SE	pH=7.4; Hard=307 mg•L^{-1}; static test; conc not measured	Cotta-Ramusino and Doci 1987

Table G-1. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Amphipod (*Gammarus fasciatus*)	Tricyclohexyltin hydroxide	96 h	LC_{50}=5 µg•L^{-1}	UN	Static test; conc not measured; other conditions NR	Johnson and Finley 1980
Copepod (*Daphnia magna*)	Tricyclohexyltin hydroxide	48 h	LC_{50}=0.17 µg•L^{-1} (0.12–2.26)	UN	Static test; conc not measured; other conditions NR	Johnson and Finley 1980
Cladoceran (*Daphnia pulex*) (<24 h old)	Triphenyltin hydroxide	48 h	EC_{50}=13.8 µg•L^{-1} (immobilization)	SE	Static test; 23.2°C; Hard=46.5 mg•L^{-1}; pH=7.1–7.8	Kline *et al.* 1989
	Triphenyltin hydroxide	48 h	EC_{50}=15.7 µg•L^{-1} (immobilization)	SE	Static test; 23.2°C; Hard=46.5 mg•L^{-1}; pH=7.1–7.8	Kline *et al.* 1989
Cladoceran (*Ceriodaphnia dubia*) (<24 h old)	Triphenyltin hydroxide	48 h	EC_{50}=10.8 µg•L^{-1} (immobilization)	SE	Static test; 23.2°C; Hard=46.5 mg•L^{-1}; pH=7.1–7.8	Kline *et al.* 1989
Cladoceran (*Daphnia magna*) (life cycle)	Bis(tributyltin) oxide	21 d	LOEL=0.2 µg•L^{-1} (reproduction)	PR	Static renewal test; conc measured; Hard=50.7–52.1 mg•L^{-1}; pH=7.46–7.57; 22.4°C–25.9°C	Brooke *et al.* 1986

Table G-2. Summary of Acute and Chronic Organotin Toxicity Data for Estuarine and Marine Invertebrates

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Copepod (*Eurytemora affinis*)	Tributyltin chloride	48 h	LC_{50}=2.2 µg•L^{-1}	PR	Sal=10 g•L^{-1}; 20°C; photoperiod=16L:8D; TBT measured every 24 h; static test	Hall *et al.* 1988a
	Tributyltin chloride	72 h	LC_{50}=0.6 µg•L^{-1}	PR	Sal=10 g•L^{-1}; 20°C; photoperiod=16L:8D; TBT measured every 24 h; static test	Hall *et al.* 1988a
Hard clam (*Mercenaria mercenaria*) (embryo)	Tributyltin chloride	24 h	LC_{50}=>1.16 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
	Tributyltin chloride	48 h	LC_{50}=1.01 µg•L^{-1} (0.64–1.17)	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
Hard clam (*Mercenaria mercenaria*) (larva)	Tributyltin chloride	24 h	LC_{50}=>3.74 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
	Tributyltin chloride	48 h	LC_{50}=1.47 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
Fiddler crab (*Uca pugilator*)	Bis(tributyltin) oxide	24 h	Retardation of regenerative limb growth, delay in ecdysis, deformities in regenerated limb caused by 0.5 µg•L^{-1}	UN	Sal=25 g•L^{-1}; solutions renewed 3 times per week; conc not measured; other conditions NR	Weis *et al.* 1987
Oyster Aldrich (*Crassostrea gigas*) (spat)	Bis(tributyltin) oxide	1–2 h	0.01 µg•L^{-1} caused significant reduction in ability of spat to compensate for hypoxia; 0.01 µg•L^{-1} was lowest conc tested	SE	conc not measured; static test	Lawler and Aldrich 1987
Oyster (*Crassostrea virginica*) (embryo)	Tributyltin chloride	24 h	LC_{50}=>1.23 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
	Tributyltin chloride	48 h	LC_{50}=1.16 µg•L^{-1} (0.69–1.22)	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987

[1] Unless otherwise indicated, all concentrations reported for primary and secondary studies are the concentration of the organotin cation. Tests with compounds that contained less than 95% organotin active ingredient were corrected accordingly. Data from unacceptable studies are as published.

Hard = hardness as mg•L^{-1} $CaCO_3$
Sal = salinity
L:D = light/dark hours
conc = concentration
NR = not reported
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian interim water qualilty guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Oyster (*Crassostrea virginica*) (embryo) (cont'd)	Tributyltin chloride	48 h	LC_{50}=0.71 µg•L^{-1} (0.63–1.07)	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
Oyster (*Crassostrea virginica*) (larvae)	Tributyltin chloride	24 h	LC_{50}=>3.74 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
	Tributyltin chloride	48 h	LC_{50}=3.52 µg•L^{-1}	PR	Static renewal test; conc measured; 20°C or 24°C; Sal=18–22 g•L^{-1}	Roberts 1987
Copepod (*Nitocra spinipes*)	Bis(tributyltin) oxide	96 h	LC_{50}=1.9 µg•L^{-1}	SE	Sal=7 g•L^{-1}; pH=7.8; 10°C; static test; conc not measured	Linden *et al.* 1979
	Tributyltin fluoride	96 h	LC_{50}=1.9 µg•L^{-1}	SE	Sal=7 g•L^{-1}; pH=7.8; 10°C; static test; conc not measured	Linden *et al.* 1979
Lobster (*Homarus americanus*) (larvae)	Bis(tributyltin) oxide	24 h	LC_{100}=19 µg•L^{-1}	SE	Static test; conc not measured	Laughlin and French 1980
Lobster (*Homarus americanus*) (4th stage)	Bis(tributyltin) oxide	NR	1–10 µg•L^{-1} was toxic	UN		Jones *et al.* 1982
Sand shrimp (*Crangon crangon*) (larvae)	Bis(tributyltin) oxide	96 h	LC_{50}=1.5 µg•L^{-1}	UN	Static renewal test; other conditions NR	Thain 1983
Shore crab (*Carcinus maenus*) (larvae)	Bis(tributyltin) oxide	96 h	LC_{50}=10 µg•L^{-1}	UN	Static renewal test; other conditions NR	Thain 1983
Polychaete (*Neanthes arenaceodentata*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=6.81 µg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
Polychaete (*Neanthes arenaceodentata*) (adult)	Bis(tributyltin) oxide	96 h	LC_{50}=21.4 µg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
Mussel (*Mytilus edulis*) (adult)	Bis(tributyltin) oxide	96 h	LC_{50}=34.1 µg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
Oyster (*Crassostrea virginica*) (embryo)	Bis(tributyltin) oxide	96 h	LC_{50}=0.89 µg•L^{-1}	UN	Sal=18–22 g•L^{-1}; static test; conc not measured	EG&G Bionomics 1977
Clam (*Mercenaria mercenaria*) (post-larva)	Tributyltin chloride	96 h	LC_{50}=0.015 µg•L^{-1}	UN	Static test; conc not measured	Becerra-Huencho 1984
Mysid shrimp (*Acanthomysis sculpta*) (juvenile)	Tributyltin	96 h	LC_{50}=0.42 µg•L^{-1}	PR	Static renewal test; organisms exposed to leachate from panels coated with antifouling paint containing tributyltin polymer and cuprous oxide; conc measured	Davidson *et al.* 1986a, 1986b

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Mysid shrimp (*Acanthomysis sculpta*) (juvenile) (cont'd)	Tributyltin	96 h	LC_{50}=0.61 μg•L^{-1}	PR	Flow-through test; conc measured; TBT from painted panels	Valkirs *et al.* 1985a
Mysid shrimp (*Acanthomysis sculpta*) (adult)	Tributyltin	96 h	LC_{50}=1.68 μg•L^{-1}	PR	Flow-through test; conc measured; TBT from painted panels	Valkirs *et al.* 1985a
Mysid shrimp (*Metamysidopsis elongata*) (juvenile)	Bis(tributyltin) oxide	96 h	LC_{50}=<0.97 μg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
(subadult)	Bis(tributyltin) oxide	96 h	LC_{50}=1.95 μg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
(adult)	Bis(tributyltin) oxide	96 h 96 h	LC_{50}=6.8 ug•L^{-1} LC_{50}=2.43 μg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
Amphipod (*Orchestia traskiana*) (adult)	Bis(tributyltin) oxide	96 h	LC_{50}=>14.6 μg•L^{-1}	UN	Static renewal test; Sal=30 g•L^{-1}; conc measured	Laughlin *et al.* 1982b
	Tributyltin fluoride	96 h	LC_{50}=>14.1 μg•L^{-1}	UN	Static renewal test; Sal=30 g•L^{-1}; conc measured	Laughlin *et al.* 1982b
Mud crab (*Rhithropanopeus harrisii*) (larva)	Tributyltin sulphide	96 h	LC_{50}=34.9 μg•L^{-1}	UN	Static renewal test; Sal=15 g•L^{-1}; conc not measured	Laughlin *et al.* 1983
	Bis(tributyltin) oxide	96 h	LC_{50}=24.3 μg•L^{-1}	UN	Static renewal test; Sal=15 g•L^{-1}; conc not measured	Laughlin *et al.* 1983
Shrimp (*Acanthomysis sculpta*)	Bis(tributyltin) oxide	96 h	LC_{50} between 0.6 and 2.9 μg•L^{-1}	SE	Particulates in water from contaminated San Diego Bay sediments; conc measured; static test	Salazar and Salazar 1985a
Copepod (*Acartia tonsa*)	Bis(tributyltin) oxide	24 h 24 h 72 h 72 h 96 h 96 h	EC_{50}=2.2 μg•L^{-1} LC_{50}=3.0 μg•L^{-1} EC_{50}=0.75 μg•L^{-1} LC_{50}=2.1 μg•L^{-1} EC_{50}=0.65 μg•L^{-1} LC_{50}=1.0 μg•L^{-1}	UN	Static renewal test; conc measured; 20°C; other conditions NR	U'ren 1983
Clam (*Mercenaria mercenaria*) (post-larva)	Tributyltin chloride	96 h	0.00073 μg•L^{-1} inhibited swimming behaviour; 0.0029 μg•L^{-1} reduced number of animals developing a foot	UN	Static test; conc not measured	Becerra-Huencho 1984
(larva)	Bis(tributyltin) oxide	8 h	LC_{35}=0.6 μg•L^{-1}	SE	Static renewal test; conc measured	Laughlin *et al.* 1987

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
(post-larva)	Bis(tributyltin) oxide	25 h	LC$_{100}$=9.5 µg•L^{-1}; 7.5 µg•L^{-1} produced better survival than in controls	SE	Flow-through test; conc measured	Laughlin *et al.* 1987
Clam (*Protothaca stamina*) (adult)	Bis(tributyltin) oxide	96 h	100% survival at greater than 2.92 µg•L^{-1}	UN	Sal=33–34 g•L^{-1}; static test; conc not measured	Salazar and Salazar (undated)
Copepod (*Acartia tonsa*)	Bis(tributyltin) oxide	96 h	LC$_{50}$=1.0 µg•L^{-1}	UN	Particulates in water from contaminated San Diego Bay sediments; conc measured; static test	Salazar and Salazar 1985b
Grass shrimp (*Palaemonetes pugio*)	Bis(tributyltin) oxide	40 min	No avoidance of 30 µg•L^{-1} total organic tin	PR	Flow-through test; conc measured; 22°C–27.5°C; Sal=9.9–11.2 g•L^{-1}	Pinkney *et al.* 1985
	Bis(tributyltin) oxide	96 h	LC$_{50}$=19.5 µg•L^{-1}	PR	Flow-through test; conc measured	Clark *et al.* 1987
	Triphenyltin oxide	96 h	LC$_{50}$=48.9 µg•L^{-1}	PR	Flow-through test; conc measured	Clark *et al.* 1987
Amphioxus (*Branchiostoma caribaeum*)	Bis(tributyltin) oxide	96 h	LC$_{100}$=9.73 µg•L^{-1}	PR	Flow-through test; conc measured	Clark *et al.* 1987
Shrimp (*Crangon crangon*)	Triphenyltin acetate	48 h	LC$_{50}$=>33 mg•L^{-1}	UN	Static renewal test; conc not measured; 15°C	Portmann and Wilson 1971
Clam (*Mercenaria mercenaria*) (veligers)	Bis(tributyltin) oxide	48 h	LC$_{50}$=0.9–2.4 µg•L^{-1}	SE	Flow-through test; conc measured; 25°C; Sal=32 g•L^{-1}	Laughlin *et al.* 1989
Oyster (*Crassostrea gigas*) (larva)	Bis(tributyltin) oxide	96 h	LC$_{50}$=1.557 µg•L^{-1}	UN	Static renewal test; other conditions NR	Thain 1983
(adult)	Bis(tributyltin) oxide	96 h	LC$_{50}$=282.2 µg•L^{-1}	UN	Static renewal test; other conditions NR	Thain 1983
Mussel (*Mytilus edulis*) (larva)	Bis(tributyltin) oxide	96 h	LC$_{50}$=2.238 µg•L^{-1}	UN	Static renewal tests; other conditions NR	Thain 1983
Mussel (*Mytilus edulis*) (adult)	Bis(tributyltin) oxide	96 h	LC$_{50}$=37.0 µg•L^{-1}	UN	Static renewal tests; other conditions NR	Thain 1983
Lugworm (*Arenicola cristata*) (larvae)	Triphenyltin oxide	96 h	4 µg•L^{-1} killed 20 out of 20 larvae; 2 µg•L^{-1} killed 1 out of 20 larvae; all 20 larvae survived at 1.5 µg•L^{-1} but had abnormal development	UN	Static test; 20°C conc not measured; other conditions NR	Walsh *et al.* 1986

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Lugworm (*Arenicola cristata*)	Triphenyltin chloride	96 h	10 $\mu g \cdot L^{-1}$ killed 20 out of 20 larvae; all 20 larvae survived 2.5 $\mu g \cdot L^{-1}$ but 6 out of 20 had abnormal development	UN	Static test; 20°C conc not measured; other conditions NR	Walsh *et al.* 1986
	Bis(tributyltin) oxide	96 h	4 $\mu g \cdot L^{-1}$ killed 20 out of 20 larvae; all 20 larvae survived 2 $\mu g \cdot L^{-1}$	UN	Static test; 20°C; conc not measured; other conditions NR	Walsh *et al.* 1986
Copepod (*Eurytemora affinis*) (subadult)	Tributyltin chloride	48 h	LC_{50}=1.4 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	48 h	LC_{50}=2.5 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	72 h	LC_{50}=0.6 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	72 h	LC_{50}=0.5 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
Copepod (*Acartia tonsa*) (subadult)	Tributyltin chloride	48 h	LC_{50}=1.1 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
Amphipod (*Gammarus* sp.) (young)	Tributyltin chloride	48 h	LC_{50}=12.5 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	72 h	LC_{50}=4.3 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	96 h	LC_{50}=1.3 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
Amphipod (*Gammarus* sp.) (adult)	Tributyltin chloride	48 h	LC_{50}=20.2 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	72 h	LC_{50}=10.1 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	96 h	LC_{50}=5.3 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
Grass shrimp (*Palaemonetes* sp.) (subadult)	Tributyltin chloride	48 h	LC_{50}=>32.2 $\mu g \cdot L^{-1}$	PR	Sal=10 $g \cdot L^{-1}$; 20°C; flow-through test; conc measured	Bushong *et al.* 1988

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Grass shrimp (*Palaemonetes* (sp.) (subadult) (cont'd)	Tributyltin chloride	72 h	LC_{50}=>31 µg•L^{-1}	PR	Sal=10 g•L^{-1}; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
	Tributyltin chloride	96 h	LC_{50}=>31 µg•L^{-1}	PR	Sal=10 g•L^{-1}; 20°C; flow-through test; conc measured	Bushong *et al.* 1988
Dog-whelk (*Nucella lapillus*) (adult)	Tributyltin	120 d	41% imposex (superimposition of male anatomical characteristics on females) at 0.019 µg•L^{-1}	SE	Organisms exposed to leachate from panels coated with anti-fouling paint	Bryan *et al.* 1986
Mud snail (*Nassarius obsoletus*) (adult)	Bis(tributyltin) oxide	35–75 d	Imposex induced in female snails; 0.02% suspension	UN	Sal=23 g•L^{-1}; static test; conc not measured; other conditions NR	Smith 1981a
	Tributyltin chloride	56 d	EC_{10}=4.5–5.5 µg•L^{-1} for induction of imposex; LC_{10}=5.5 µg•L^{-1} LC_{50}=7.5 µg•L^{-1}	UN	Sal=16–20 g•L^{-1}; static test; conc not measured; other conditions NR	Smith 1981b
Copepod (*Acartia tonsa*)	Bis(tributyltin) oxide	120 h 120 h 144 h 144 h	EC_{50}=0.50 µg•L^{-1} LC_{50}=0.75 µg•L^{-1} EC_{50}=0.40 µg•L^{-1} LC_{50}=0.55 µg•L^{-1}	UN	Static renewal test; conc measured; 20°C; other conditions NR; reduced activity	U'ren 1983
Mussel (*Mytilus edulis*) (spat)	Tributyltin	45 d	Significant reduction in growth; no mortality in 0.24 µg•L^{-1}; 100% mortality at 2.6 µg•L^{-1}	UN	Flow-through test; conc measured; TBT from painted panels; Sal=28.5–34.2 g•L^{-1}; other conditions NR	Thain and Waldock 1985; Thain 1986
Mussel (*Mytilus edulis*) (larva)	Bis(tributyltin) oxide	15 d	LC_{50}=0.1 µg•L^{-1}; reduced growth of survivors at 0.0973 µg•L^{-1}	UN	Sal=33 g•L^{-1}; static renewal test; conc measured; 15°C; other conditions NR	Beaumont and Budd 1984
Mussel (*Mytilus edulis*) (2.5–4.1 cm)	Tributyltin	66 d	Significantly decreased growth in shell by 0.31 µg•L^{-1}	PR	Flow-through test; conc measured; TBT from painted panels	Valkirs *et al.* 1985a
Oyster (*Crassostrea gigas*) (spat)	Tributyltin	45 d	LC_{40}=0.24 µg•L^{-1} reduced growth of survivors	UN	Flow-through test; conc measured; TBT from painted panels; Sal=28.5–34.2 g•L^{-1}; other conditions NR	Thain and Waldock 1985; Thain 1986
	Tributyltin	45 d	LC_{90}=2.6 µg•L^{-1}	UN	Flow-through test; conc measured; TBT from painted panels; Sal=28.5–34.2 g•L^{-1}; other conditions NR	Thain and Waldock 1985; Thain 1986

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Oyster (*Crassostrea gigas*) (larva)	Tributyltin	30 d	LC$_{100}$=2.0 µg•L^{-1}	UN		Alzieu *et al.* 1980
	Tributyltin	113 d	LC$_{30}$=0.2 µg•L^{-1}	UN		Alzieu *et al.* 1980
	Tributyltin fluoride	21 d	Reduced number of normally developed larvae and setting spat at 0.0235 µg•L^{-1}	UN	Sal=18–21 g•L^{-1}	Springborn Bionomics 1984
	Tributyltin fluoride	15 d	LC$_{100}$=0.0472 µg•L^{-1}	UN	Sal=18–21 g•L^{-1}	Springborn Bionomics 1984
Oyster (*Crassostrea virginica*) (2.7–5.3 cm)	Tributyltin	67 d	Decrease in body weight at 0.73 µg•L^{-1}; no effect on survival at 1.89 µg•L^{-1}	PR	Flow-through test; conc measured; TBT from painted panels	Valkirs *et al.* 1985a
Oyster (*Crassostrea virginica*) (adult)	Tributyltin	57 d	Decrease in condition index at 0.1 µg•L^{-1}	UN	Flow-through test; conc measured; TBT from painted panels; Sal=33–36 g•L^{-1}; copper leached from panels	Henderson 1986
	Tributyltin	30 d	LC$_{50}$=2.5 µg•L^{-1}	UN	Flow-through test; conc measured; TBT from painted panels; Sal=33–36 g•L^{-1}; copper leached from panels	Henderson 1986
Oyster (*Crassostrea virginica*)	Tributyltin	56 d	Significant mortality at 1.0 µg•L^{-1}	UN	Flow-through test; conc measured; other conditions NR; TBT levels fluctuated in treatments	Roberts 1987
Oyster (*Ostrea edulis*) (spat)	Bis(tributyltin) oxide	20 d	Significant growth retardation at 0.01946 µg•L^{-1}	UN	Sal=30 g•L^{-1}; other conditions NR	Thain and Waldock 1985
	Tributyltin	45 d	Decreased growth at 0.239 µg•L^{-1}; 70% mortality at 2.6 µg•L^{-1}	UN	Sal=28.5–34.2 g•L^{-1}; flow-through test; conc measured; TBT from painted panels; other conditions NR	Thain and Waldock 1985; Thain 1986
Oyster (*Ostrea edulis*) (adult)	Tributyltin	75 d	Complete inhibition of larval production at 0.24 µg•L^{-1} and retardation of sex change; 2.6 µg•L^{-1} prevented gonadal development	UN	Sal=28.5–34.2; flow-through test; conc measured; TBT from painted panels; other conditions NR	Thain 1986
Mussel (*Mytilus edulis*) (juvenile)	Tributyltin	84 d	Mean conc of 0.20 µg•L^{-1} or greater caused significant reductions in growth rates	PR	Field study; conc measured	Salazar and Salazar 1988

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Fiddler crab (*Uca pugilator*)	Tributyltin	7 d	Deformities in regenerating limbs significant when exposure to 5.0 $\mu g \cdot L^{-1}$ occurred during 2nd-week of 4-week regeneration time; same as continuous exposure for 4 weeks.	UN	No clear pattern of effect with 1-week exposures to 0.5 $\mu g \cdot L^{-1}$ during 4-week regeneration time; 0.5 $\mu g \cdot L^{-1}$ also produced deformities; conc not measured; static test; other conditions NR	Weis and Kim 1988
Mussel (*Mytilus edulis*)	Tributyltin chloride	30 d	0.7 $\mu g \cdot L^{-1}$ caused about 50% mortality; serum protein increased with time of exposure	UN	TBT from painted panels in flowing seawater; other conditions NR	Pickwell and Steinert 1988
Oyster (*Crassostrea virginica*)	Tributyltin chloride	30 d	0.7 $\mu g \cdot L^{-1}$ caused "virtually no deaths"; serum protein did not increase with time of exposure	UN	TBT from painted panels in flowing seawater; other conditions NR	Pickwell and Steinert 1988
Clam (*Mercenaria mercenaria*) (post-larva)	Bis(tributyltin) oxide	25 d	LC_{50}=7.1–9.5 $\mu g \cdot L^{-1}$	SE	Flow-through test; conc measured; 25°C; Sal=32 $g \cdot L^{-1}$	Laughlin *et al.* 1989
(veligers)	Bis(tributyltin) oxide	8 d	No significant growth at 0.6 $\mu g \cdot L^{-1}$	SE	Static renewal test; conc measured; 25°C; Sal=32 $g \cdot L^{-1}$	Laughlin *et al.* 1988
Clam (*Mercenaria mercenaria*) (embryos)	Bis(tributyltin) oxide	14 d	No metamorphosis occurred at 0.1 $\mu g \cdot L^{-1}$; growth inhibition occurred at 0.010 $\mu g \cdot L^{-1}$	SE	Static renewal test; conc measured; 25°C; Sal=32 $g \cdot L^{-1}$	Laughlin *et al.* 1988
Lugworm (*Arenicola cristata*) (larvae)	Triphenyltin oxide	168 h	2 $\mu g \cdot L^{-1}$ killed 20 out of 20 larvae; all 20 larvae survived 1.5 $\mu g \cdot L^{-1}$ but had abnormal development; NOEL=0.5 $\mu g \cdot L^{-1}$	UN	Static test; 20°C conc not measured; other conditions NR	Walsh *et al.* 1986
	Triphenyltin chloride	168 h	5 $\mu g \cdot L^{-1}$ killed 20 out of 20 larvae; all 20 larvae survived 2.5 $\mu g \cdot L^{-1}$ but had abnormal development; NOEL=0.5 $\mu g \cdot L^{-1}$	UN	Static test; 20°C conc not measured; other conditions NR	Walsh *et al.* 1986
Lugworm (*Arenicola cristata*) (larvae)	Bis(tributyltin) oxide	168 h	5 $\mu g \cdot L^{-1}$ killed 20 out of 20 larvae; NOEL=0.5 $\mu g \cdot L^{-1}$	UN	Static test; 20°C conc not measured; other conditions NR	Walsh *et al.* 1986

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Copepod (*Eurytemora affinis*)	Tributyltin chloride	13 d	0.2 μg•L^{-1} caused significant decrease in survival; no significant effects at 0.0125–0.1 μg•L^{-1}	PR	Sal=10 g•L^{-1}; 20°C; photoperiod=16L:8D; conc measured 3 times per week; flow-through tests	Hall *et al.* 1988a
Copepod (*Acartia tonsa*) (nauplii <24 h old)	Tributyltin chloride	6 d	LOEL for survival was 0.023–0.024 μg•L^{-1}	PR	Sal=10.5–11.9 g•L^{-1}; 20.1°C–21.4°C; pH=8.21–8.44; flow-through test; conc measured	Bushong *et al.* 1990
Mud crab (*Rhithropanopeus harrisii*) (zoeae)	Trimethyltin hydroxide	14 d	LC$_{50}$=92 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Triethyltin hydroxide	14 d	LC$_{50}$=80.7 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Tripropyltin oxide	14 d	LC$_{50}$=92.4 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Triisopropyltin oxide	14 d	LC$_{50}$=90 μg•L^{-1}	SE	Sal=15 g•L^{-1} 25°C; static test; renewed; daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Tributyltin oxide	14 d	LC$_{50}$=31.1 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Triisobutyltin oxide	14 d	LC$_{50}$=26 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Triphenyltin hydroxide	14 d	LC$_{50}$=34 μg•L^{-1}	SE	Sal=15 g•L^{-1} 25°C; static test; renewed; daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Tricyclohexyltin bromide	14 d	LC$_{50}$=7.2 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Dimethyltin dichloride	14 d	LC$_{50}$=13.7 mg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Diethyltin dichloride	14 d	LC$_{50}$=2.58 mg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Dipropyltin dichloride	14 d	LC$_{50}$=2.86 mg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Dibutyltin dichloride	14 d	LC$_{50}$=661 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Mud crab (*Rhithropanopeus harrissii*) (zoeae) (cont'd)	Diphenyltin dichloride	14 d	LC_{50}=701 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Dicyclohexyltin dichloride	14 d	LC_{50}=100 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
	Dibenzyltin dichloride	14 d	LC_{50}=7468 μg•L^{-1}	SE	Sal=15 g•L^{-1}; 25°C; static test; renewed daily; conc not measured	Laughlin *et al.* 1984a, 1985b; Laughlin 1987
Brittle star (*Ophioderma brevispina*)	Bis(tributyltin) oxide, triphenyltin oxide	28 d	Arm regeneration inhibited by 0.1 μg•L^{-1}	UN	Flow-through test; conc measured; 20°C Sal=20 g•L^{-1}; other conditions NR	Walsh *et al.* 1986
Oyster (*Crassostrea gigas*) (adult)	Bis(tributyltin) oxide	56 d	0.15 μg•L^{-1} decreased growth; pronounced thickening of upper shell valve	UN	18°C; Sal=29–32 g•L^{-1}; static test; conc measured; other conditions NR	Waldock and Thain 1983
	Bis(tributyltin) oxide	56 d	1.6 μg•L^{-1} caused severe growth inhibition in survivors	UN	18°C; Sal=29–32 g•L^{-1}; static test; conc measured; other conditions NR	Waldock and Thain 1983
Bay mussel (*Mytilus edulis*)	Tributyltin	66 d	LC_{50}=0.97 μg•L^{-1}	PR	TBT leached from painted (SPC-954 antifouling paint) panels; conc measurements made 14 times during test; Sal=32 g•L^{-1}; flow-through test	Valkirs *et al.* 1985a
Oyster (*Crassostrea virginica*)	Tributyltin	67 d	0.73–1.89 μg•L^{-1} caused body weight decrease; 0.04–0.31 μg•L^{-1} did not cause effects	PR	TBT leached from painted (SPC-954 antifouling paint) panels; conc measurements made 14 times during test; Sal=32 g•L^{-1}; flow-through test	Valkirs *et al.* 1985a
Bay mussel (*Mytilus edulis*) (juvenile)	Bis(tributyltin) oxide	7 d	0.4 μg•L^{-1} and greater caused significant reductions in length growth rate	UN	Flow-through test; conc not measured; Sal=33.7 g•L^{-1}; 8°C; other conditions NR	Stromgren and Bongard 1987
Oyster (*Crassostrea gigas*) (spat)	Bis(tributyltin) oxide	14 d	0.049 μg•L^{-1} caused significant increases in O_2 consumption, decreases in feeding rate; 0.02 μg•L^{-1} did not affect O_2 consumption or feeding rate	SE	Static test; conc not measured	Lawler and Aldrich 1987

Table G-2. Continued

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Oyster (*Crassostrea gigas*) (spat) (cont'd)	Bis(tributyltin) oxide	48 d	0.019 $\mu g{\bullet}L^{-1}$ caused significant reduction in growth at 20°C; 0.01 $\mu g{\bullet}L^{-1}$ did not affect growth rate; shell thickening observed at 0.01 $\mu g{\bullet}L^{-1}$	SE	Static test; conc not measured	Lawler and Aldrich 1987
Amphipod (*Gammarus oceanicus*) (adults)	Bis(tributyltin) oxide, tributyltin fluoride	10–12d	LC_{50}=2.8 $\mu g{\bullet}L^{-1}$	SE	Static renewal test; conc not measured; 10°C–15°C; Sal=7 $g{\bullet}L^{-1}$	Laughlin *et al.* 1984b
	Bis(tributyltin) oxide, tributyltin fluoride	56 d	LC_{100}=2.8 $\mu g{\bullet}L^{-1}$	SE	Static renewal test; conc not measured; 10°C–15°C; Sal=7 $g{\bullet}L^{-1}$	Laughlin *et al.* 1984b
Amphipod (*Gammarus oceanicus*) (larvae)	Bis(tributyltin) oxide, tributyltin fluoride	56 d	0.28 $\mu g{\bullet}L^{-1}$ caused significant decrease in larval survival	SE	Static renewal test; conc not measured; 10°C–15°C; Sal=7 $g{\bullet}L^{-1}$	Laughlin *et al.* 1984b
Lobster (*Homarus americanus*) (larvae)	Bis(tributyltin) oxide	to 6 d	4.7–14 $\mu g{\bullet}L^{-1}$ acutely toxic	SE	Static test; conc not measured	Laughlin and French 1980
	Bis(tributyltin) oxide	to 6 d	0.9 $\mu g{\bullet}L^{-1}$ caused no effect on larval metamorphosis	SE	Static test; conc not measured	Laughlin and French 1980
Amphipod (*Orchestoidea californiana*)	Bis(tributyltin) oxide	9 d	5.7, 9.5, and 14 $\mu g{\bullet}L^{-1}$ produced 53%, 20%, and 7% survival	SE	Static renewal test	Laughlin *et al.* 1982a
Mysid shrimp (*Acanthomysis sculpta*)	Tributyltin	63 d	LOEL=0.19 $\mu g{\bullet}L^{-1}$ (production of young)	PR	Organisms exposed to leachate from panels coated with antifouling paint containing tributyltin polymer and cuprous oxide; conc measured; flow-through test	Davidson *et al.* 1986a, 1986b
Amphipod (*Gammarus* sp.)	Tributyltin chloride	24 d	Mortality at 0.58 $\mu g{\bullet}L^{-1}$ same as control; growth responses had inconsistent dose/response relationship	SE	20°C; Sal=9.7–10.7 $g{\bullet}L^{-1}$; pH=8.3; flow-through test; conc measured	Hall *et al.* 1988c

Appendix H
Summary of Organotin Toxicity Data for Freshwater, Estuarine, and Marine Algae

Table H-1. Summary of Organotin Toxicity Data for Freshwater Algae

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Green alga (*Ankistrodesmus falcatus*)	Trimethyltin chloride	4 h	IC_{50}=5.5 mg•L^{-1}	SE	IC_{50}=conc causing 50% reduction in ^{14}C-HCO_3 uptake in CHU-10 media; conc not measured	Wong *et al.* 1982
	Triethyltin bromide	4 h	IC_{50}=0.2 mg•L^{-1}	SE		
	Tripropyltin chloride	4 h	IC_{50}=0.02 mg•L^{-1}	SE		
	Tributyltin chloride	4 h	IC_{50}=0.02 mg•L^{-1}	SE		
	Triphenyltin chloride	4 h	IC_{50}=0.01 mg•L^{-1}	SE		
	Dimethyltin dichloride	4 h	IC_{50}=21 mg•L^{-1}	SE		
	Diethyltin dichloride	4 h	IC_{50}=16 mg•L^{-1}	SE		
	Dibutyltin dichloride	4 h	IC_{50}=6.8 mg•L^{-1}	SE		
	Diphenyltin dichloride	4 h	IC_{50}=8.0 mg•L^{-1}	SE		
	Monomethyltin trichloride	4 h	IC_{50}=23.0 mg•L^{-1}	SE		
	Monobutyltin trichloride	4 h	IC_{50}=25.0 mg•L^{-1}	SE		
	Monophenyltin trichloride	4 h	IC_{50}=19.0 mg•L^{-1}	SE		
Green alga (*Scenedesmus quadricauda*)	Trimethyltin chloride	4 h	IC_{50}=2.6 mg•L^{-1}	SE	IC_{50}=conc causing 50% reduction in ^{14}C-HCO_3 uptake in CHU-10 media; conc not measured	Wong *et al.* 1982
	Triethyltin chloride	4 h	IC_{50}=0.1 mg•L^{-1}	SE		
	Tributyltin chloride	4 h	IC_{50}=0.016 mg•L^{-1}	SE		
	Triphenyltin chloride	4 h	IC_{50}=0.04 mg•L^{-1}	SE		
	Dimethyltin dichloride	4 h	IC_{50}=4.1 mg•L^{-1}	SE		
Blue-green alga (*Anabaena flos-aquae*)	Trimethyltin chloride	4 h	IC_{50}=>5000 mg•L^{-1}	SE	IC_{50}=conc causing 50% reduction in ^{14}C-HCO_3 uptake in CHU-10 media; conc not measured	Wong *et al.* 1982
	Tributyltin chloride	4 h	IC_{50}=0.013 mg•L^{-1}	SE		
	Triphenyltin chloride	4 h	IC_{50}=0.02 mg•L^{-1}	SE		

[1] Unless otherwise indicated, all concentrations reported for primary and secondary studies are the concentration of the organotin cation. Tests with compounds that contained less than 95% organotin active ingredient were corrected accordingly.

conc = concentration
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian interim water quality guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table H-1. Continued

Organism	Organotin compound	Exposure time	Effects	Test rank	Comments	Reference
Blue-green alga (*Anabaena* (*flos-aquae*) (cont'd)	Dimethyltin dichloride	4 h	IC_{50}=>5000 mg•L^{-1}	SE		
	Tributyltin chloride	14 d	LC_{100}=0.223 mg•L^{-1}	SE	Conc not measured; static test	Wangberg and Blanck 1988
Blue-green alga (*Anabaena* sp.)	Tributyltin chloride	14 d	LC_{100}=0.111 mg•L^{-1}	SE	Conc not measured; Static test	Wangberg and Blanck 1988
Lake Ontario indigenous phytoplankton assemblage (species not given)	Trimethyltin chloride	4 h	IC_{50}=0.35 mg•L^{-1}	SE	IC_{50}=conc causing 50% reduction in ^{14}C-HCO_3 uptake; conc not measured	Wong *et al.* 1982
	Triethyltin bromide	4 h	IC_{50}=0.055 mg•L^{-1}	SE		
	Tripropyltin chloride	4 h	IC_{50}=0.004 mg•L^{-1}	SE		
	Tributyltin chloride	4 h	IC_{50}=0.003 mg•L^{-1}	SE		
	Triphenyltin chloride	4 h	IC_{50}=0.002 mg•L^{-1}	SE		
Blue-green alga (*Oscillatoria* sp.)	Tributyltin chloride	14 d	No growth at 223 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Blue-green alga (*Synechococcus leopoliensis*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Chlamydomonas dysosmas*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Chlorella emersonii*)	Tributyltin chloride	14 d	No growth at 445 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Kirchneriella contoria*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Monoraphidium pusillum*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Scenedesmus obtusiusculus*)	Tributyltin chloride	14 d	No growth at 445 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Green alga (*Selenastrum capricornutum*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Yellow-green alga (*Bumilleriopsis filiformis*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986

Table H-1. Continued

Organism	Organotin compound	Exposure time	Effects	Test rank	Comments	Reference
Yellow-green alga (*Monodus subterraneous*)	Tributyltin chloride	14 d	No growth at 1.78 mg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Yellow-green alga (*Tribonema aequele*)	Tributyltin chloride	14 d	No growth at 111 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Yellow-green alga (*Klebsormidium morinum*)	Tributyltin chloride	14 d	No growth at 223 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986
Golden alga (*Raphidonema longiseta*)	Tributyltin chloride	14 d	No growth at 56.1 µg•L^{-1}	SE	250-µL cultures in microtitration plates; conc not measured	Blanck *et al.* 1984; Blanck 1986

Table H-2. Summary of Organotin Toxicity Data for Estuarine and Marine Algae

Organism	Organotin compound	Exposure time	Effects[1]	Test rank	Comments	Reference
Diatom (*Skeletonema costatum*)	Bis(tributyltin) oxide	5 d	Algistatic at 0.97–17.5 µg•L^{-1}; algicidal at >17.5 µg•L^{-1}	UN	Test procedures inadequately reported	Thain 1983
		14 d	EC_{50}=0.063 µg•L^{-1}	UN	Conc causing 50% decrease in dry cell weight	EG&G Bionomics 1981a
Green alga (*Dunaliella* sp.)	Bis(tributyltin) oxide	72 h	LC_{50} approx. 1.46 µg•L^{-1}; LC_{100}=2.92 µg•L^{-1}	SE	Conc not measured	Salazar 1985
Diatom (*Phaeodactylum tricornutum*)	Bis(tributyltin) oxide	72 h	No effect on growth at 1.46–5.84 µg•L^{-1}	SE	Conc not measured	Salazar 1985
Dinoflagellate (*Gymnodinium splendens*)	Bis(tributyltin) oxide	72 h	LC_{100}=1.46 µg•L^{-1}	SE	Conc not measured	Salazar 1985
Diatom (*Skeletonema costatum*)	Methyltin trichloride	72 h	EC_{50}=42.6–43.7 µg•L^{-1}	SE	Conc causing 50% decrease in population growth; conc not measured	Walsh *et al.* 1985, 1987; Walsh 1986
	Trimethyltin chloride	72 h	EC_{50}=173–176 µg•L^{-1}	SE		
	Triethyltin bromide	72 h	EC_{50}=3.17–3.24 µg•L^{-1}	SE		
	Tetraethyltin	72 h	EC_{50}=142–148 µg•L^{-1}	SE		
	Dibutyltin diacetate	72 h	EC_{50}=22.8–24.1 µg•L^{-1}	SE		
	Dibutyltin dichloride	72 h	EC_{50}=37–44.1 µg•L^{-1}	SE		
	Dibutyltin difluoride	72 h	EC_{50}=47.9–52.7 µg•L^{-1}	SE		
	Tributyltin acetate	72 h	EC_{50}=0.30–0.35 µg•L^{-1}	SE		
	Tributyltin fluoride	72 h	EC_{50}=0.32–0.35 µg•L^{-1}	SE		
	Tributyltin chloride	72 h	EC_{50}=0.35–0.365 µg•L^{-1}	SE		
	Tetrabutyltin	72 h	EC_{50}=17.2–17.4 µg•L^{-1}	SE		
	Diphenyltin dichloride	72 h	EC_{50}=20.1–24.8 µg•L^{-1}	SE		

[1] Unless otherwise indicated, all concentrations reported are the concentration of the organotin cation.

Sal = salinity
conc = concentration
PR = primary study, which may be included in minimum data set for Canadian water quality guidelines or interim guidelines
SE = secondary study, which may be included in minimum data set for Canadian water quality guidelines
UN = unacceptable study, which cannot be included in minimum data set for Canadian water quality guidelines or interim guidelines

Table H-2. Continued

Organism	Organotin compound	Exposure time	Effects	Test rank	Comments	Reference
Diatom (*Skeletonema costatum*) (cont'd)	Triphenyltin chloride	72 h	EC_{50}=0.77–0.79 µg•L^{-1}	SE		
	Triphenyltin hydroxide	72 h	EC_{50}=0.63–0.69 µg•L^{-1}	SE		
	Bis(triphenyltin) oxide	72 h	EC_{50}=0.79–0.84 µg•L^{-1}	SE		
Diatom (*Thalassiosira pseudonana*)	Monomethyltin trichloride	72 h	EC_{50}=190–192 µg•L^{-1}	SE	Conc causing 50% decrease in population growth; conc not measured	Walsh *et al.* 1985, 1987; Walsh 1986
	Trimethyltin chloride	72 h	EC_{50}=284–287 µg•L^{-1}	SE		
	Triethyltin bromide	72 h	EC_{50}=2.74–2.81 µg•L^{-1}	SE		
	Tetraethyltin	72 h	EC_{50}=116–121 µg•L^{-1}	SE		
	Dibutyltin dichloride	72 h	EC_{50}=131–133 µg•L^{-1}	SE		
	Dibutyltin difluoride	72 h	EC_{50}=270–276 µg•L^{-1}	SE		
	Tributyltin acetate	72 h	EC_{50}=1.08 µg•L^{-1}	SE		
	Tributyltin oxide	72 h	EC_{50}=1.07 µg•L^{-1}	SE		
	Diphenyltin dichloride	72 h	EC_{50}=28.5–29.6 µg•L^{-1}	SE		
	Triphenyltin acetate	72 h	EC_{50}=1.03–1.11 µg•L^{-1}	SE		
	Triphenyltin chloride	72 h	EC_{50}=1.18–1.27 µg•L^{-1}	SE		
	Triphenyltin hydroxide	72 h	EC_{50}=1.14 µg•L^{-1}	SE		
	Bis(triphenyltin) oxide	72 h	EC_{50}=1.27 µg•L^{-1}	SE		
Diatom (*Skeletonema costatum*)	Methyltin trichloride	72 h	LC_{50}=>279 µg•L^{-1}	SE	Death of individual cells determined by staining; conc not measured	Walsh *et al.* 1985
	Dimethyltin dichloride	72 h	LC_{50}=>371 µg•L^{-1}	SE		
	Triethyltin bromide	72 h	LC_{50}=29.0 µg•L^{-1}	SE		
	Tetraethyltin	72 h	LC_{50}=>500 µg•L^{-1}	SE		
	Dibutyltin dichlorde	72 h	LC_{50}=>383 µg•L^{-1}	SE		
	Dibutyltin diacetate	72 h	LC_{50}=>332 µg•L^{-1}	SE		

Table H-2. Continued

Organism	Organotin compound	Exposure time	Effects	Test rank	Comments	Reference
Diatom (*Skeletonema costatum*) (cont'd)	Tributyltin acetate	72 h	LC_{50}=12.2 µg•L^{-1}	SE		
	Bis(tributyltin) oxide	72 h	LC_{50}=13.8 µg•L^{-1}	SE		
	Tributyltin chloride	72 h	LC_{50}=10.2 µg•L^{-1}	SE		
	Tributyltin fluoride	72 h	LC_{50}=11.2 µg•L^{-1}	SE		
	Tetrabutyltin	72 h	LC_{50}=>500 µg•L^{-1}	SE		
	Diphenyltin dichloride	72 h	LC_{50}=>397 µg•L^{-1}	SE		
	Triphenyltin acetate	72 h	LC_{50}=14.4 µg•L^{-1}	SE		
	Bis(triphenyltin oxide	72 h	LC_{50}=4.18 µg•L^{-1}	SE		
	Triphenyltin chloride	72 h	LC_{50}=12.5 µg•L^{-1}	SE		
	Triphenyltin hydroxide	72 h	LC_{50}=13.3 µg•L^{-1}	SE		
Benthic microalga (*Pavlova lutheri*)	Bis(tributyltin) oxide	3 h	0.97 µg•L^{-1} caused significant increase in respiration	SE	Conc measured; static test; conc varied	Beaumont *et al.* 1987
Benthic macroalga (*Ulva lactuca*)	Bis(tributyltin) oxide	3 h	0.097 µg•L^{-1} caused significant increase in respiration	SE	Conc measured; static test; conc varied	Beaumont *et al.* 1987
Diatom (*Amphora coffeaeformis*)	Tributyltin fluoride	30 min	29.0 µg•L^{-1} caused reduced uptake of nitrate, phosphate, and silicate	SE	Static test; conc not measured	Thomas and Robinson 1987
Benthic microalga (*Pavlova lutheri*)	Bis(tributyltin) oxide	26 d	0.097 µg•L^{-1} significantly reduced growth	PR	Static test; conc measured; 19°C; Sal=34–40 g•L^{-1}	Beaumont and Newman 1986
Benthic microalga (*Dunaliella tertiolecta*)	Bis(tributyltin) oxide	26 d	0.097 µg•L^{-1} significantly reduced growth	PR	Static test; conc measured 19°C; Sal=34–40 g•L^{-1}	Beaumont and Newman 1986
Benthic microalga (*Skeletonema costatum*)	Bis(tributyltin) oxide	26 d	0.097 µg•L^{-1} significantly reduced growth	PR	Static test; conc measured 19°C; Sal=34–40 g•L^{-1}	Beaumont and Newman 1986

Appendix I

Summary of Rat and Mouse Acute Oral Tributyltin Toxicity Data

Table I-1. Summary of Rat and Mouse Acute Oral Tributyltin Toxicity Data

Animal	Tributyltin anion	LD_{50}[1]	Reference
Rat	Fluoride	94	Schweinfurth 1985; Schweinfurth and Gunzel 1987
	Chloride	122	
	Oxide	127	
	Benzoate	99/203	
	Linoleate	190	
	Abietate	158	
	Naphthenate	224	
Mouse	Chloride	117	Pelikan and Cerny 1968; Politou *et al.* 1978
	Benzoate	108	
	Acetate	46	
	Oleate	230	
	Laurate	108	
	Oxide	152(M)/92(F)	

M = male
F = female
[1] Milligrams of tributyltin plus anion per kilogram body weight.

Appendix J

Summary of Repeated-Dose Oral Toxicity Studies with Tributyltin Compounds

Table J-1. Summary of Repeated-Dose Oral Toxocity Studies with Tributyltin Compounds

Compound	Route	Duration	Species	Animals/ group	Dose levels	Comments	Reference
Tributyltin acetate	Feed	90 d	Rat	12M (?)	25 ppm	No effects observed	Barnes and Stoner 1958
					50 ppm	Growth retardation	
					100 ppm	Mortality (2/12), bile duct inflammation	
Tributyltin acetate	Intragastric	28 d (24 doses)	Rat	24 pups (12M/12F)	$1\ \mathrm{mg{\cdot}kg^{-1}}$	No effects observed	Mushak *et al.* 1982
					$3\ \mathrm{mg{\cdot}kg^{-1}}$	Death in 9/24 pups, inflammation of hepatic bile duct	
					$10\ \mathrm{m{\cdot}kg^{-1}}$	Death in 17/24 pups, inflammation of hepatic bile duct, no central nervous system changes	
					$30\ \mathrm{m{\cdot}kg^{-1}}$	Death after 5–8 doses	
Tributyltin chloride	Feed	2 weeks	Rat	10M	15 ppm	"Thymus and spleen weight decreased" (questionable, see Schweinfurth 1986)	Snoeij *et al.* 1985
					50 ppm	Lymphocytes of thymic cortex decreased; rosettes in mesenteric lymph node	
					150 ppm	Feed intake and body weight decreased	
Tributyltin chloride	Feed	4 weeks	Rat	6M (10x6M)	100 ppm	Thymus weight decreased	Snoeij *et al.* 1985
					Recovery	Normal after 1 week	
Tributyltin chloride	Feed	2 weeks	Mouse	10M	50 ppm	No effects observed	Snoeij *et al.* 1987b
					150 ppm	Feed intake, body weight, thymus and spleen weight decreased	
Bis(tributyltin) oxide	Feed	7 d	Young mouse	10M	77 ppm	Weight gain decreased, spleen weight decreased	Ishaaya *et al.* 1976
		4 d	Adult mouse	4M	232 ppm 696 ppm	Body weight decreased, white blood cell and lymphocyte count decreased	

M = male
F = female
Source: Adapted from Schweinfurth and Gunzel 1987.

Table J-1. Continued

Compound	Route	Duration	Species	Animals/ group	Dose levels	Comments	Reference
Bis(tributyltin) oxide	Feed	30 d	Rat	10M	32 ppm	Weight gain decreased	Elsea and Paynter 1958
					100 ppm	Weight gain decreased	
					320 ppm	Food consumption decreased, mortality (6/10), no macroscopic changes	
Bis(tributyltin) oxide	Intragastric	10–11 d	Rat	10M/10F	1 mg•kg^{-1}	No effects observed	Schweinfurth 1986
					25 mg•k^{-1}	Mortality (2M/2F), microcytic anemia, chronic inflammation of bile duct, lymphotoxicity	
Bis(tributyltin) oxide	Feed	4 weeks (range-finding)	Rat	5M/5F	4 ppm	No effects observed	Schweinfurth 1985
					20 ppm	No effects observed	
					100 ppm	Food consumption and weight gain decreased, thymus weight decreased (M)	Schweinfurth 1985
					500 ppm	High mortality, apathy, emaciation, thymus and lymph node weight decreased, lymphocyte depletion in lymphatic organs	

Appendix K
Summary of Mammalian Acute Oral Triphenyltin Toxicity Data

Table K-1. Summary of Mammalian Acute Oral Triphenyltin Toxicity Data

Animal	Triphenyltin anion	LD_{50}[1]
Rat	Acetate	136–491
	Chloride	125–135
	Hydroxide	110–360
	Oxide	155
Mouse	Acetate	81–93.3
	Chloride	80–90
	Hydroxide	80–619
	Oxide	1000
Guinea pig	Acetate	10–41.2
	Hydroxide	25–31.1
Rabbit	Acetate	30–140

[1] In milligrams of triphenyltin plus anion per kilogram body weight.

Source: Bock 1981.

Appendix L
Chronic Studies of the Effect of Organotin Compounds on Domestic Animals

Table L-1. Chronic Studies of the Effect of Organotin Compounds on Domestic Animals

Compound	Route	Duration (years)	Species	Animals/ group	Dose level	Effect	References
Triphenyltin hydroxide	Feed	2	Rats	6×25M+F	0.5 ppm	No observed effect	Til *et al.* 1970
					1.0 ppm	No observed effect	
					2.0 ppm	No observed effect	
					5.0 ppm	No observed effect	
					10 ppm	Slightly decreased thyroid gland weight, lower number of leucocytes in 1st year, and slightly higher mortality rate (F)	
Triphenyltin acetate	Feed	2	Guinea pigs	7×10M/10F	1.0 ppm	No observed effect	Weigand and Kief 1965; Weigand 1975
					5.0 ppm	No observed effect	
					10 ppm	Fat deposits appeared in cells of liver and heart	
					50 ppm	100% mortality in 16 weeks, weight loss, fat deposits appeared in cells of liver and heart	
					100 ppm	100% mortality in 16 weeks, weight loss, fat deposits appeared in cells of liver and heart	
					200 ppm	100% mortality in 16 weeks, weight loss, fat deposits appeared in cells of liver and heart	
Triphenyltin acetate	Feed	2	Beagles	3M/3F	0.5 ppm	No observed effect	Scholtz and Brunk 1968
					1.0 ppm	No observed effect	
					5.0 ppm	Slightly lower weight gain	
Triphenyltin hydroxide	Feed	2	Beagles	4×3M/3F	0.5 ppm	No observed effect	Til and Feron 1968
					2.5 ppm	No observed effect	
					5.0 ppm	Relative weight of liver and kidneys and water content of brain slightly higher than those of controls	
					10.0 ppm	Relative weight of liver and kidneys and water content of brain slightly higher than those of controls	

M = male
F = female
Source: Adapted from Bock 1981.

Appendix M
Phytotoxicity of Triphenyltin Compounds for Various Plants

Table M-1. Phytotoxicity of Triphenyltin Compounds for Various Plants

Plant	Triphenyltin compound	Concentration or amount	Phytotoxicity	Reference
Tomato	Acetate	0.1%–1%	Slightly to highly toxic	Baumann 1958
	Acetate	0.08%	Toxic	Picco 1957, 1958, 1965
	Hydroxide, acetate, chloride etc.	50–100 ppm	Toxic	Haertel 1962
	Hydroxide	0.2–0.3 kg•ha^{-1}	Toxic	Schroeder 1963
	Acetate, hydroxide, chloride, chloride complexes	250–1000 ppm	Toxic	Schicke *et al.* 1968
	Chloride	25–250 µg•cm^{-2}	Very toxic	Kubo 1965
	Phosphoric acid ester	25–250 µg•cm^{-2}	Very toxic	Kubo 1965
Eggplant	Acetate, hydroxide, chloride, oxide, sulphide, disulphide	0.05%	Not toxic	Ascher and Meisner 1969
Watermelon	Hydroxide	0.3 kg•ha^{-1}	Toxic	Schenk and Crall 1963
Cucumber	Hydroxide	0.38 kg•ha^{-1}	Toxic	Sitterly 1963a, 1963b
	Phosphoric acid ester	25–250 µg•cm^{-2}	Very toxic	Kubo 1965
Radish	Phosphoric acid ester	25–250 µg•cm^{-2}	Very toxic	Kubo 1965
Soybean	Phosphoric acid ester	25–250 ppm	Slightly toxic	Kubo 1965
Bean	Acetate, hydroxide, chloride, chloride complexes	250–1000 ppm	Slightly toxic	Schicke *et al.* 1968
Bush bean	Acetate	0.1%–1%	Slightly to highly toxic	Baumann 1958
	Acetate	0.05%	Not toxic	Andren and Olofsson 1959
	Acetate	0.05%–0.25%	Not toxic	Schmidt 1962a, 1962b
Kohlrabi	Acetate	0.1%–1%	Slightly to highly toxic	Baumann 1958
Carrot	Acetate	0.04%–0.06%	Not toxic	Schmidt 1965
Carrot	Acetate	—	Not toxic	Ascher and Nissim 1964
	Acetate	0.04%–0.06%	Not toxic	Franz 1972
Grape vine	Acetate	0.1%–1%	Distinctly to highly toxic	Baumann 1958

Source: Adapted from Bock 1981.

Table M-1. Continued

Plant	Triphenyltin compound	Concentration or amount	Phytotoxicity	Reference
Grape vine (cont'd)	Acetate	—	Toxic	Haertel 1958, 1962
Hops	Acetate	0.1%–1%	Distinctly to highly toxic	Baumann 1958
Fruit	Acetate	—	Toxic	Haertal 1958
Tobacco	Acetate	63–500 ppm	Slightly to moderately toxic	Kubo 1965
	Phosphoric acid ester	63–500 ppm	Slightly to moderately toxic	Kubo 1965
	Acetate	0.005%–0.08%	Toxic	Kroeber and Massfeller 1961
	Acetate	0.008%	Moderately toxic	de Baets 1961
Flax	Acetate	30–120 $g \cdot ha^{-1}$	Highly toxic	Estienne and Hennebert 1959
Barley	Acetate	25–250 $\mu g \cdot cm^{-3}$	Slightly to highly toxic	Kubo 1965
	Phosphoric acid ester	25–250 $\mu g \cdot cm^{-3}$	Slightly to highly toxic	Kubo 1965
Alfalfa	Acetate	—	Slightly toxic	Ascher and Rones 1964

Appendix N
Minimum Toxicity Data Set Worksheets for the Protection of Freshwater and Marine Aquatic Life

APPENDIX N-1.

Minimum Toxicity Data Set Worksheets for the Protection of Freshwater Aquatic Life.

The organotin compounds examined include:

(a) (b) (c) (d) (e)	monomethyltin dimethyltin trimethyltin monobutyltin dibutyltin	References are 1. Wester and Canton (1987)
(f)	tributyltin	References are 1. Brooke *et al.* (1986) 2. Martin *et al.* (1989)
(g) (h) (i)	monophenyltin diphenyltin triphenyltin	Reference is 1. Jarvinen *et al.* (1988)

(g) (h) (i)	monophenyltin diphenyltin triphenyltin	Reference is 1. Jarvinen *et al.* (1988)

Appendix N-1(a)

Water Use: Protection of Freshwater Aquatic Life

Compound: Monomethyltin (MMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.					
	2.					
	3.					
Invertebrates	1.					
	2.					
Plants	1.					

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(b)

Water Use: Protection of Freshwater Aquatic Life

Compound: Dimethyltin (DMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.					
	2.					
	3.					
Invertebrates	1.					
	2.					
Plants	1.					

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(c)

Water Use: Protection of Freshwater Aquatic Life

Compound: Trimethyltin (TMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.		___	___	___	___
	2.		___	___	___	___
	3.		___	___		___
Invertebrates	1.		___	___	___	___
	2.		___	___	___	___
Plants	1.		___	___		___

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(d)

Water Use: Protection of Freshwater Aquatic Life

Compound: Monobutyltin (MBT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.		____	____	____	____
	2.		____	____	____	____
	3.		____	____		____
Invertebrates	1.		____	____	____	____
	2.		____	____	____	____
Plants	1.		____	____		____

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(e)

Water Use: Protection of Freshwater Aquatic Life

Compound: Dibutyltin (DBT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Resident in North America	Chronic study	Reference
Fish	1. *Poecilia reticulata*	X		X	1
	2.				
	3.				
Invertebrates	1.				
	2.				
Plants	1.				

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(f)

Water Use: Protection of Freshwater Aquatic Life

Compound: Tributyltin (TBT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.	*Pimephales promelas*	X	X	X	1
	2.	*Oncorhyncus mykiss*	X	X		2
	3.	*Salvelinus namaycush*	X	X		2
Invertebrates	1.	*Daphnia magna*	X	X	X	1
	2.	*Hydra* sp.	X	X		1
Plants	1.					

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes X No ___

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes X No ___

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes X No ___

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes X No ___

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes X No ___

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes X No ___

(2) Is one fish species a cold-water species resident in North America? Yes X No ___

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes X No ___

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(g)

Water Use: Protection of Freshwater Aquatic Life

Compound: Monophenyltin (MPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.					
	2.					
	3.					
Invertebrates	1.					
	2.					
Plants	1.					

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(h)

Water Use: Protection of Freshwater Aquatic Life

Compound: Diphenyltin (DPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.		____	____	____	____
	2.		____	____	____	____
	3.		____	____		____
Invertebrates	1.		____	____	____	____
	2.		____	____	____	____
Plants	1.		____	____		____

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes ___ No X

(2) Is one fish species a cold-water species resident in North America? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-1(I)

Water Use: Protection of Freshwater Aquatic Life

Compound: Triphenyltin (TPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Resident in North America	Chronic study	Reference
Fish	1.	*Pimephales promelas*	X	X	X	1
	2.					
	3.					
Invertebrates	1.					
	2.					
Plants	1.					

(1) Do the above studies include at least one cold- and warm-water freshwater species? Yes ___ No X

(2) Do the above studies include at least two classes of freshwater invertebrates? Yes ___ No X

(3) Do the above studies include at least one planktonic freshwater invertebrate species? Yes ___ No X

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for fish, and for invertebrates? Yes X No ___

(2) Is one fish species a cold-water species resident in North America? Yes X No ___

(3) Are the two invertebrate species from different classes, and is one species planktonic and resident in North America? Yes X No ___

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N

Minimum Toxicity Data Set Worksheets for the Protection of Freshwater and Marine Aquatic Life

Appendix N-2.

Minimum Toxicity Data Set Worksheets for the Protection of Marine Aquatic Life

The organotin compounds examined include:

(a) monomethyltin
(b) dimethyltin
(c) trimethyltin
(d) monobutyltin
(e) dibutyltin
(f) tributyltin

References are
1. Hall *et al.* (1988c)
2. Pinkney *et al.* (1985)
3. Davidson *et al.* (1986a, 1986b)
4. Hall *et al.* (1988a)
5. Beaumont and Newman (1986)

(g) monophenyltin
(h) diphenyltin
(i) triphenyltin

Reference is
1. Clark *et al.* (1987)

Appendix N-2(a)

Water Use: Protection of Marine Aquatic Life

Compound: Monomethyltin (MMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	___	___	___		___
	2.	___	___	___		___
	3.	___	___			___
Invertebrates	1.	___	___	___	___	___
	2.	___	___	___		___
Plants	1.	___	___			___

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(b)

Water Use: Protection of Marine Aquatic Life

Compound: Dimethyltin (DMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	____	____	____		____
	2.	____	____	____		____
	3.	____	____			____
Invertebrates	1.	____	____	____	____	____
	2.	____	____	____		____
Plants	1.	____	____			____

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(c)

Water Use: Protection of Marine Aquatic Life

Compound: Trimethyltin (TMT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	______	______	______		______
	2.	______	______	______		______
	3.	______	______			______
Invertebrates	1.	______	______	______	______	______
	2.	______	______	______		______
Plants	1.	______	______			______

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ____ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(d)

Water Use: Protection of Marine Aquatic Life

Compound: Monobutyltin (MBT)

Canadian Water Quality <u>Guideline</u> Requirements: Minimum <u>Toxicity</u> Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	___	___	___		___
	2.	___	___	___		___
	3.	___	___			___
Invertebrates	1.	___	___	___	___	___
	2.	___	___	___		___
Plants	1.	___	___			___

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality <u>Guideline</u> Requirements: Minimum <u>Environmental Fate</u> Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes X No ___

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes X No ___

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality <u>Interim Guideline</u> Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(e)

Water Use: Protection of Marine Aquatic Life

Compound: Dibutyltin (DBT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	____	____	____		____
	2.	____	____	____		____
	3.	____	____			____
Invertebrates	1.	____	____	____	____	____
	2.	____	____	____		____
Plants	1.	____	____			____

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes X No ___

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes X No ___

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(f)

Water Use: Protection of Marine Aquatic Life

Compound: Tributyltin (TBT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1. *Menidia berylina*	X	X	X		1
	2. *Brevoortia tyrannus*	X	X	X		1
	3. *Fundulus heteroclitus*	X	X			2
Invertebrates	1. *Acanthomysis sculpta*	X	X	X	X	3
	2. *Eurytemora affinis*	X	X	X		4
Plants	1. *Pavlova lutheri*	X	X			5

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes X No ___ If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes X No ___

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes X No ___

(3) Are the eventual chemical metabolites known? Yes X No ___

(4) Is the persistence of the compound in water, sediments, and biota known? Yes X No ___

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No ___

(2) Is one fish species a temperate species? Yes ___ No ___

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No ___

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(g)

Water Use: Protection of Marine Aquatic Life

Compound: Monophenyltin (MPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	____	____	____		____
	2.	____	____	____		____
	3.	____	____			____
Invertebrates	1.	____	____	____	____	____
	2.	____	____	____		____
Plants	1.	____	____			____

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes ___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(h)

Water Use: Protection of Marine Aquatic Life

Compound: Diphenyltin (DPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota	Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.	____	____	____		____
	2.	____	____	____		____
	3.	____	____			____
Invertebrates	1.	____	____	____	____	____
	2.	____	____	____		____
Plants	1.	____	____			____

Are there scientifically justified exemptions to above requirements? Yes ___ No X
Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes __ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes ___ No X

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ____ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.

Appendix N-2(I)

Water Use: Protection of Marine Aquatic Life

Compound: Triphenyltin (TPT)

Canadian Water Quality Guideline Requirements: Minimum Toxicity Data Set

Aquatic biota		Species	Primary	Temperate species	Chronic study	Two classes represented	Reference
Fish	1.						
	2.						
	3.						
Invertebrates	1.	*Palaemonetes pugio*	X	X			1
	2.						
Plants	1.						

Are there scientifically justified exemptions to above requirements? Yes ___ No X

Are the minimum toxicity data set requirements met? Yes ___ No X If no, go to interim guideline section.

Canadian Water Quality Guideline Requirements: Minimum Environmental Fate Data Set

(1) Are the mobility of the compound and the compartments of the aquatic environment in which it is likely to be found known? Yes___ No X

(2) Are the kinds of chemical and biological reactions that take place during transport and after deposition known? Yes ___ No X

(3) Are the eventual chemical metabolites known? Yes ___ No X

(4) Is the persistence of the compound in water, sediments, and biota known? Yes ___ No X

If the answer is no to any of the above, go to interim guideline section.

Canadian Water Quality Interim Guideline Requirements:

(1) Are there at least two acute and/or chronic studies for marine fish, and for marine invertebrates? Yes ___ No X

(2) Is one fish species a temperate species? Yes X No ___

(3) Are the two invertebrate species from different classes, and is one of the species temperate? Yes ___ No X

If the answer is no to any of the above, then an interim guideline cannot be calculated. Primary or secondary studies may be used for the interim guideline data requirements.