AMBIENT AQUATIC LIFE WATER QUALITY ADVISORIES FOR

TRIBUTYLTIN

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL RESEARCH LABORATORIES
DULUTH, MINNESOTA
NARRAGANSETT, RHODE ISLAND

FOREWORD

The Criteria and Standards Division of the Office of Water Regulations and Standards has instituted water quality advisories as a vehicle for transmitting the best available scientific information concerning the aquatic life and human health effects of selected chemicals in surface waters. Advisories are prepared for chemicals for which information is needed quickly, but for which sufficient data, resources, or time are not available to allow derivation of national ambient water quality criteria.

Data supporting advisories are usually not as extensive as required for derivation of national ambient water quality criteria, and the strength of an advisory will depend upon the amount, type, and reliability of the data available. We feel, however, that it is in the best interest of all concerned to make the enclosed information available to those who need it.

Users of an advisory should take into account its basis and intended uses. Anyone who has additional information that will supplement or substantially change an advisory is requested to make the information known to us. An advisory for an individual chemical will be revised if any significant and valid new data make it necessary.

We invite comments to help improve this product.

Edmund M. Notzon, Director
Criteria and Standards Division

iii

ACKNOWLEDGMENTS

CONTENTS

TABLES

INTRODUCTION

The Water Quality Advisory Document has been developed to provide technical guidance and the best available scientific data on the adverse effects of chemicals in surface waters. Advisory concentrations represent levels of contaminants in surface waters and drinking water at which adverse effects to human health and aquatic life would not be anticipated to occur. An advisory may be issued for any chemical when there is need for information but where insufficient data exist to calculate a national ambient water quality criterion.

An ambient water quality advisory concentration for the *protection of aquatic life will be derived from aquatic toxicity* data in accordance with the procedures describes in the Guidelines for Deriving Aquatic Life Advisory Concentrations.

An ambient water quality advisory concentration for the protection of human health may be derived from a number of sources: The Office of Drinking Water Health Advisories; Agency verified Reference Dose (RfD) values; Office of Pesticides and Toxic Substances risk estimates; risk estimates originating from open literature or other sources which will be cited in the support document.

Prior to application of an advisory concentration, the user should carefully review the supportive data within the advisory document and develop an understanding of the derivation of the advisory recommendation.

Background Information

Organotins are compounds consisting of one to four organic moieties attached to a tin atom via carbon-tin covalent bonds. When there are fewer than four carbon-tin bonds, the organotin compound will be a cation unless the remaining valences of tin are occupied by an anion such as acetate, carbonate, chloride, fluoride, hydroxide, oxide, or sulfide. Thus a species such as TBT is a cation whose formula is $(C_4H_9)_3Sn^+$. In sea water TBT exists mainly as a mixture of the chloride, the hydroxide, the aquo complex, and the carbonate complex (Laughlin et al. 1986a).

The toxicities of organotin compounds are related to the number of organic moieties bonded to the tin atom and to the number of carbon atoms in the organic moieties. Toxicity to aquatic species generally increases as the number of organic moieties increases from one to three and decreases with the incorporation of a fourth, making triorganotins more toxic than other forms. Within the triorganotins, toxicity increases as the number of carbon atoms in the organic moiety increases from one to four, then decreases. Thus the most toxic organotin to aquatic life is tributyltin (Hall and Pinkney 1985; Laughlin and Linden 1985; Laughlin et al. 1985).

Organotins are used in several manufacturing processes, for example, as an anti-yellowing agent in clear plastics and as a catalyst in poly(vinyl chloride) products (Piver 1973). One of the more extensive uses of organotins

3

is as biocides, and it is this use that will probably contribute most significantly to direct release of organotins into the aquatic environment (Hall and Pinkney 1985; Kinnetic Laboratory 1984).

The U.S. Navy (1984) proposed application of some paints containing TBT to hulls of naval ships. Such paint formulations have been shown to be an effective and relatively long-lived deterrent to adhesion of barnacles and other fouling organisms. Encrustations of these organisms on ships' hulls reduce maximum speed and increase fuel consumption. According to the U.S. Navy (1984), use of TBT paints would not only reduce fuel consumption by 15% but would also increase time between repainting from less than 5 years to 5 to 7 years. Release of TBT to water would occur during repainting in shipyards when old paint is sand-blasted off and new paint applied. TBT would also be released continuously from the hulls of the painted ships. Antifouling paints in current use contain copper as the primary biocide, whereas the proposed TBT paints would contain both copper and TBT. Interaction between the toxicities of TBT and other ingredients in the paint apparently is negligible (Davidson et al. 1986a).

The solubility of TBT compounds in water is influenced by such factors as the oxidation-reduction potential, pH, temperature, ionic strength, and concentration and composition of the dissolved organic matter (Corbin 1976). The solubility of tributyltin oxide in water was reported to be 750 μg/L at a pH of 6.6 and 31,000 μg/L at a pH of 8.1 (Maguire et al. 1983). The carbon-tin covalent bond does not hydrolyze in water (Maguire et al. 1983,1984), and the half-life for photolysis due to sunlight is greater than 89 days (Maguire et al. 1985; Seligman et al. 1986).

TBT readily sorbs to sediments and suspended solids and can persist there (Cardarelli and Evans 1980). The half-life for desorption of TBT from sediments was reported to be greater than ten months (Maguire and Tkacz

4

1985). TBT had a half-life of about 16 weeks in a freshwater sediment (Maguire and Tkacz 1985) and 23 weeks in a saltwater sediment (Seligman et al. 1986).

Some species of algae, bacteria, and fungi have been shown to degrade TBT by sequential dealkylation, resulting in dibutyltin, then monobutyltin, and finally inorganic tin (Barug 1981; Maguire et al. 1984). Barug (1981) observed the biodegradation of TBT to di- and monobutyltin by bacteria and fungi only under aerobic conditions and only when a secondary carbon source was supplied. Maguire et al. (1984) reported that a 28-day culture of TBT with the green alga, Ankistrodesmus falcatus, resulted in 7% inorganic tin. Maguire (1986) reported that the half-life of TBT exposed to microbial degradation was five months under aerobic conditions and 1.5 months under anaerobic conditions. The major metabolite of TBT in saltwater crabs, fish, and shrimp was dibutyltin (Lee 1986).

Elevated TBT concentrations in fresh and salt waters are primarily associated with harbors and marinas (Cleary and Stebbing 1985; Hall et al. 1986; Maguire 1984,1986; Maguire and Tkacz 1985; Maguire et al. 1982; Salazar and Salazar 1985b; Seligman et al. 1986; Unger et al. 1986; Valkirs et al. 1986; Waldock and Miller 1983). In some cases the microlayer surface of the water contained a much higher concentration of TBT than the water column. Gucinski (1986) suggested that this enrichment of the surface microlayer might increase the bioavailability of TBT. No organotins were detected in the muscle tissue of feral chinook salmon caught near Auke Bay, Alaska, but concentrations as high as 900 μg/kg were reported in muscle tissue of chinook salmon held in pens treated with TBT (Short and Thrower 1986a).

Only data generated in toxicity and bioconcentration tests on TBTC (tributyltin chloride), TBTF (tributyltin fluoride), TBTO (bis(tributyltin) oxide, commonly called "tributyltin oxide") and TBTS (bis(tributyltin)

sulfide, commonly called "tributyltin sulfide") were used in the derivation of the water quality advisory concentrations for aquatic life presented herein. All concentrations from such tests are expressed as TBT, not as tin and not as the chemical tested. An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereinafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary in order to understand the following text, tables, and calculations. Results of such intermediate calculations as recalculated LC50s and Species Mean Acute Values are given to four significant figures to prevent -roundoff error in subsequent calculations, not to reflect the precision of the value. The latest comprehensive literature search for information for this document was conducted in February 1986; some more recent information was included.

Acute Toxicity to Aquatic Animals

Data that may be used, according to the Guidelines, in the derivation of Final Acute Values for TBT are presented in Table 1. Acute values are available for nine freshwater species and range from 0.5 for a hydra, Hydra sp., to 227.4 μg/L for a mosquito, Culex sp. The 96-hr LC50 of 227.4 μg/L reported by Foster (1981) for the bluegill greatly exceeds all other acute values, including those for three other species of fish. Foster's 48-hr EC50 for Daphnia magna is also much higher than the results of the two other acute tests with this species. Therefore, it seems inappropriate to use the results reported by Foster (1981) in the calculation of the freshwater Final Acute Value.

Freshwater Species Mean Acute Values (Table 1) were calculated as geometric means of the available acute values, and then Genus Mean Acute

Values (Table 3) were calculated as geometric means of the Species Mean Acute Values. Of the eight freshwater genera for which mean acute values are available, the most sensitive genus, Hydra, is 20 times more sensitive than the most resistant, Culex. The four most sensitive genera include a hydra, two fishes, and an amphipod. The freshwater Final Acute Value for TBT was calculated to be 0.2972 µg/L using the procedure described in the Guidelines and the Genus Mean Acute Values in Table 3. This Final Acute Value is lower than the lowest freshwater Species Mean Acute Value.

Tests of the acute toxicity of TBT to resident North American saltwater species that are useful for deriving water quality advisory concentrations have been performed with 16 species of invertebrates and three species of fish (Table 1). The 96-hr LC50 of 0.01466 µg/L reported by Becerra-Huencho (1984) for post larvae of the hard clam, Mercenaria mercenaria, also known as the quahog clam, was not used in the derivation of the mean acute value for this species because results of other studies with embryos, larvae, and post larvae of the hard clam (Tables 1 and 6) cast doubt on this LC50. For example, Roberts (Manuscript) reported 48-hr LC50s of 1.13 µg/L for embryos and 1.65 µg/L for larvae of the hard clam. Laughlin et al. (1987) observed about 35% mortality of larval hard clams exposed for eight days to 0.6 µg/L and reduced growth after 14 days in 0.025 µg/L. They found that post larvae were more resistant than larvae; concentrations $\leq$ 7.5 µg/L did not reduce survival after 25 days, but 10 µg/L caused 100% mortality. Results from these tests, in which concentrations of TBT were measured, differ markedly from the LC50 of 0.01466 µg/L that was obtained in a test in which the concentrations were not measured. The LC50 reported by Becerra-Huencho (1984) appears to be low because all other data for embryo, larval, and

7

post-larval clams, mussels, and oysters indicate that acutely lethal concentrations are in the range of 0.6 to 4.0 μg/L.

Except for the LC50 reported by Becerro-Huencho (1984), the range of acute toxicity to saltwater animals is a factor of about 670. Acute values range from 0.42 μg/L for juveniles of the mysid, Acanthomysis sculpta (Davidson et al. 1986a,b) to 282.2 μg/L for adult Pacific oysters, Crassostrea gigas (Thain 1983). The 96-hr LC50s for three saltwater fish species range from 1.460 μg/L for juvenile chinook salmon, Oncorhynchus tshawytscha (Short and Thrower 1986b) to 23.36 μg/L for adult mummichogs, Fundulus heteroclitus (EG&G Bionomics 1976).

Larval bivalve molluscs and juvenile crustaceans appear to be much more sensitive than adults during acute exposures. The 96-hr LC50 for larval Pacific oysters was 1.557 μg/L, whereas the value for adults was 282.2 μg/L (Thain 1983). In renewal tests, the 96-hr LC50s for larval and adult blue mussels, Mytilus edulis, were 2.238 and 36.98 μg/L, respectively (Thain 1983). Juveniles of the crustaceans Acanthomysis sculpta and Metamysidopsis elongata were slightly more sensitive to TBT than adults (Davidson et al. 1986a,b; Valkirs et al. 1985; Salazar and Salazar, Manuscript).

Genus Mean Acute Values are available for 18 saltwater genera and range from 0.61 μg/L for Acanthomysis to 204.4 μg/L for Ostrea (Table 3). Genus Mean Acute Values for the 11 most sensitive genera differ by a factor of less than four. Included within these genera are four species of molluscs, six species of crustraceans, and two species of fish. The saltwater Final Acute Value for TBT was calculated to be 0.5313 μg/L (Table 3), which is lower than the lowest saltwater Species Mean Acute Value.

Chronic Toxicity to Aquatic Animals

The available data that are usable according to the Guidelines concerning the chronic toxicity of TBT are presented in Table 2. Brooke et al. (1986) reported that the survival of Daphnia magna was 40% at a TBT concentration of 0.5 µg/L, and 100% at 0.2 µg/L. The mean number of young was reduced 30% by 0.2 µg/L, and was reduced 6% by 0.1 µg/L. The chronic value for Daphnia magna was calculated to be 0.1414 µg/L, and the acute-chronic ratio was 30.41.

In an early life-stage test with the fathead minnow, Pimephales promelas, all fish exposed to 2.20 µg/L died during the test (Brooke et al. 1986). Survival was reduced by 2% at a TBT concentration of 0.92 µg/L, but was higher than in the controls at 0.45 µg/L and lower concentrations. The mean weight of the surviving fish was reduced 4% at 0.08 µg/L, 9% at 0.15 µg/L, 26% at 0.45 µg/L, and 48% at 0.92 µg/L. The mean biomass at the end of the test was higher at 0.08 and 0.15 µg/L than in the controls, but was reduced by 13 and 52% at TBT concentrations of 0.45 and 0.92 µg/L, respectively. Because the reductions in weight were small and the mean biomass increased at 0.08 and 0.15 µg/L, the chronic limits are 0.15 and 0.45 µg/L. Thus the chronic value is 0.2598 µg/L and the acute-chronic ratio is 10.01.

Life-cycle toxicity tests have been conducted with the saltwater mysid, Acanthomysis sculpta (Davidson et al. 1986a,b) and the sheepshead minnow, Cyprinodon variegatus (Ward et al. 1981). The effects of TBT on survival, growth, and reproduction of A. sculpta were determined in four separate tests lasting from 28 to 63 days. The number of juveniles released per female at a TBT concentration of 0.19 µg/L was 50% of the number released in the control treatment, whereas the number released at 0.09 µg/L was higher than in the control treatment. The data concerning the effects of TBT on survival

9

and growth are not easy to interpret. At concentrations from 0.08 to 0.27 μg/L, survival and weight were sometimes equal to or better than in the control treatment, but at concentrations of 0.38 μg/L and above, survival and weight were always reduced by at least 23%. The chronic value is 0.1308 μg/L, and the acute-chronic ratio is 4.664 (Table 2).

In the life-cycle test conducted with the estuarine fish _Cyprinodon variegatus_ (Ward et al. 1981), mean measured concentrations were 240 to 300% of the nominal concentrations in the first 34 days and 45 to 112% of nominals in the remainder of this 177-day test. In the same publication, measured concentrations were 18 to 32% of nominals during a 21-day lethality test and 80% of nominal during a bioconcentration test. No data were used from this publication because the various ratios of the measured and nominal concentrations of TBT in the different tests suggest that problems existed in the delivery of TBT or in the analytical chemistry or both.

The Final Acute-Chronic Ratio of 11.24 was calculated as the geometric mean of the acute-chronic ratios of 30.41 for _Daphnia magna_, 10.01 for _Pimephales promelas_, and 4.664 for _Acanthomysis sculpta_. Division of the freshwater and saltwater Final Acute Values by 11.24 results in freshwater and saltwater Final Chronic Values of 0.02644 and 0.04727 μg/L, respectively (Table 3). Both of these Final Chronic Values are below the experimentally determined chronic values.

Unacceptable effects on commercially important saltwater molluscs occurred at TBT concentrations less than 0.04727 μg/L (Table 6). Growth or development of the Pacific oyster, European flat oyster, and hard clam was reduced at 0.023; 0.019, and 0.025 μg/L, respectively. A TBT concentration of 0.047 μg/L was lethal to larval _C. gigas_. Because adverse effects on important saltwater species have been documented to occur at concentrations as

10

low as 0.019 μg/L, the saltwater Final Chronic Value is lowered to 0.010 μg/L to adequately protect these important species.

Toxicity to Aquatic Plants

Blanck et al. (1984) reported the concentrations of TBT that prevented growth of thirteen freshwater algal species (Table 4). These concentrations ranged from 56.1 to 1,782 μg/L, but most were between 100 and 250 μg/L. No data are available on the effects of TBT on freshwater vascular plants.

Toxicity tests on TBT have been conducted with five species of saltwater phytoplankton including the green alga, Dunaliella sp.; the diatoms, Phaeodactylum tricornutum, Skeletonema costatum, and Thallassiosira pseudonana; and the dinoflagellate, Gymnodinium splendens (Tables 4 and 6). The 14-day EC50 of 0.06228 μg/L for S. costatum (EG&G Bionomics 1981c) was the lowest value reported, but Thain (1983) reported that a measured concentration of 0.9732 μg/L was algistatic to the same species (Table 4). The 72-hr EC50s based on population growth ranged from approximately 0.3 to > 5.8 μg/L (Table 6). Lethal concentrations were generally more than an order-of-magnitude greater than EC50s and ranged from 1.460 to 13.82 μg/L. Identical tests conducted on tributyltin acetate, tributyltin chloride, tributyltin fluoride, and tributyltin oxide with S. costatum resulted in EC50s from 0.2346 to 0.4693 μg/L and LC50s from 10.24 to 13.82 μg/L (Walsh et al. 1985).

A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of TBT were measured and the endpoint was biologically important has been conducted with an important aquatic plant species. However, the available data indicate that freshwater and saltwater plants will be protected by concentrations that adequately protect freshwater and saltwater animals.

11

Bioaccumulation

Maguire et al. (1984) obtained bioconcentration factors (BCF) of 253 to 467 with the freshwater green alga, Ankistrodesmus falcatus (Table 5).

The extent to which TBT is accumulated by saltwater animals in tests lasting 28 days or more has been investigated with three species of bivalve molluscs (Table 5). Thain and Waldock (1985) reported a BCF of 6,833 for the soft parts of blue mussel spat exposed to 0.24 μg/L for 45 days. The highest BCF reported for a saltwater species was 11,400 for the soft parts of the Pacific oyster exposed to a TBT concentration of 0.1460 μg/L for 56 days (Waldock and Thain 1983). A BCF of 6,047 was observed for the soft parts of the Pacific oyster exposed to 0.1460 μg/L for 21 days (Waldock et al. 1983). The lowest steady-state BCF reported for a bivalve was 192.3 for the soft parts of the European flat oyster, Ostrea edulis, exposed to a TBT concentration of 2.62 μg/L for 45 days (Thain 1986; Thain and Waldock 1985).

No U.S. FDA action level or other maximum acceptable concentration in tissue, as defined in the Guidelines, is available for TBT, and, therefore, no Final Residue Value can be calculated.

Other Data

Additional data on the lethal and sublethal effects of TBT on aquatic species are presented in Table 6. Foster (1981) reported a 24-hr EC50 of 1,990 μg/L for larvae of the clam, Corbicula fluminea. This value is much higher than the acute values reported by Foster (1981) for Daphnia magna and the bluegill, which were themselves considered unusually high. Meador (1986) reported that a TBT concentration of 0.45 μg/L affected the behavior of Daphnia magna in an 8-day test. Exposures of 24 and 48 hr resulted in LC50s of 25.2 and 18.9 μg/L with rainbow trout, Salmo gairdneri (Alabaster

12

1969). Seinen et al. (1981) exposed rainbow trout to 0.18 μg/L for 110 days and observed a 20% reduction in growth. Laughlin and Linden (1982) found little difference in the toxicities of TBTF and TBTO to embryos and larvae of the frog, Rana temporaria.

The most unusual effect of TBT on saltwater animals is the superimposition of male characteristics on female stenoglossan gastropods. This phenomenon, termed "imposex," can result in females with a penis, a duct leading to a vas deferens, and the convolution of the normally straight oviduct (Smith 1981). Exposure of N. lapillus to 0.05 μg/L in a laboratory for four months produced a 41% incidence of imposex (Bryan et al. 1986). Laboratory tests with N. obsoletus and two TBT formulations also resulted in imposex but exposure conditions were not stated (Smith 1981). TBT has been linked to imposex in field populations of Nucella lapillus, Nassarius obsoletus, Nassarius reticulatus, and Ocenebra erinacea (Bryan et al. 1986; Durchon 1982; Smith 1981). Imposex has been associated with reduced reproductive capacity and altered density and population structure in field populations of N. lapillus (Bryan et al. 1986) but not of N. obsoletus (Smith 1981). Transfers of snails between clean sites and marinas contaminated with TBT demonstrated a relationship between the degree of imposex and the concentration of TBT in tissue, which suggested that snails exposed to as little as 0.0024 μg/L might be affected (Bryan et al. 1986).

Reproductive abnormalities have also been observed in the European flat oyster (Thain 1986). After exposure for 75 days to a TBT concentration of 0.24 μg/L, a retardation in the sex change from male to female was observed and larval production was completely inhibited. A TBT concentration of 2.6 μg/L prevented development of gonads.

Survival and growth of several commercially important saltwater bivalve molluscs have been studied during acute and long-term exposures to TBT.

Mortality of larval blue mussels, Mytilus edulis, exposed to 0.0973 μg/L
was 51%; survivors were moribund and stunted (Beaumont and Budd 1984). Growth
of juvenile blue mussels was significantly reduced after 7 to 66 days at 0.31
to 0.3893 μg/L (Stromgren and Bongard 1987; Valkirs et al. 1985a). The
66-day LC50 for 2.5 to 4.1 cm blue mussels was 0.97 μg/L (Valkirs et
al.1985a,1987). Growth of hard clams from fertilization to metamorphosis was
reduced by 0.025 μg/L (Laughlin et al. 1987). The number of larvae of the
Pacific oyster, Crassostrea gigas, that developed and the number of spat that
set were reduced in 21-day exposures to 0.02346 μg/L (Springborn Bionomics
1984a). Alzieu et al. (1980) reported 30% mortality and abnormal shell
thickening among Pacific oyster larvae exposed to 0.2 μg/L for 113 days.
Abnormal development was also observed in exposures of embryos for 24 hours or
less to TBT concentrations $\geq$ 0.8604 μg/L (Robert and His 1981). Waldock
and Thain (1983) observed reduced growth and thickening of the upper shell
valve of Pacific oyster spat exposed to 0.1460 μg/L for 56 days. Abnormal
shell development was observed in an exposure to 0.77 μg/L that began with
embryos of the eastern oyster, Crassostrea virginica, and lasted for 48 hours
(Roberts, Manuscript). Adult eastern oysters were also sensitive to TBT with
reductions in condition index after exposure for 57 days to $\geq$ 0.1 μg/L
(Henderson 1986; Valkirs et al. 1985a). Thain and Waldock (1985) observed a
significant reduction in growth of small spat of the European flat oyster,
Ostrea edulis, exposed for 20 days to a TBT concentration of 0.01946 μg/L.
Growth of larger spat was marginally reduced by 0.2392 μg/L (Thain 1986;
Thain and Waldock 1985).

Long-term exposures have been conducted with a number of saltwater
crustacean species. Davidson et al. (1986a,b), Laughlin et al. (1983,1984b),
and Salazar and Salazar (1985a) reported that TBT acts slowly on crustaceans
and that behavior might be affected several days before mortality occurs.

Survival of larval amphipods, Gammarus oceanicus, was significantly reduced after eight weeks of exposure to TBT concentrations $\geq$ 0.2816 μg/L (Laughlin et al. 1984b). Developmental rates and growth of larval mud crabs, Rhithropanopeus harrisii, were reduced by a 15-day exposure to $\geq$ 14.60 μg/L. R. harrisii might accumulate more TBT via ingested food than directly from water (Evans and Laughlin 1984). TBTF, TBTO, and TBTS were about equally toxic to amphipods and crabs (Laughlin et al. 1982,1983, 1984a).

Exposure of embryos of the California grunion, Leuresthes tenuis, for ten days to 74 μg/L caused a 50% reduction in hatching success (Newton et al. 1985). At TBT concentrations between 0.14 and 1.72 μg/L, growth, hatching success, and survival were significantly enhanced. Juvenile Atlantic menhaden, Brevoortia tyrannus, avoided a TBT concentration of 5.437 μg/L and juvenile striped bass, Morone saxatilis, avoided 24.9 μg/L (Hall et al. 1984). BCFs were 4,300 for liver, 1,300 for brain, and 200 for muscle tissue of chinook salmon, Oncorhynchus tshawytscha, exposed to 1.490 μg/L for 96 hours (Short and Thrower 1986a,c).

Unused Data

Some data concerning the effects of TBT on aquatic organisms were not used because the tests were conducted with species that are not resident in North America (e.g., Allen et al. 1980; Camey and Paulini 1964; Danil'chenko 1982; Deschiens and Floch 1968; Deschiens et al. 1964,1966a,b; de Sousa and Paulini 1970; Frick and DeJimenez 1964; Hopf and Muller 1962; Nishuichi and Yoshida 1972; Ritchie et al. 1964; Seiffer and Schoof 1967; Shiff et al. 1975; Tsuda et al. 1986; Upatham 1975; Upatham et al. 1980a,b; Webbe and Sturrock 1964).

Alzieu (1986), Cardarelli and Evans (1980), Cardwell and Sheldon (1986), Cardwell and Vogue (1986), Champ (1986), Chau (1986), Envirosphere Company

(1986), Good et al. (1980), Guard et al. (1982), Hall and Pinkney (1985),
Hodge et al. (1979), International Joint Commission (1976), Jensen (1977),
Kimbrough (1976), Kumpulainen and Koivistoinen (1977), Laughlin (1986),
Laughlin and Linden (1985), Laughlin et al. (1984a), McCullough et al. (1980),
Monaghan et al. (1980), North Carolina Department of Natural Resources and
Community Development (1983,1985), Seligman et al. (1986), Slesinger and
Dressler (1978), Stebbing (1985), Thayer (1984), Thompson et al. (1985), U.S.
EPA (1975,1985b), U.S. Navy (1984), Valkirs et al. (1985a), von Rumker et al.
(1974), and Walsh (1986) compiled data from other sources.

Results were not used when the test procedures, test material, or results
were not adequately described (e.g., Chau et al. 1983; Danil'chenko and
Buzinova 1982; de la Court 1980; Deschiens 1968; Filenko and Isakova 1980;
Holwerda and Herwig 1986; Kolosova et al. 1980; Laughlin 1983; Lee 1985; EG&G
Bionomics 1981b; Nosov and Kolosova 1979; Stroganov et al. 1972,1977).
Results of some laboratory tests were not used because the tests were
conducted in distilled or deionized water without addition of appropriate
salts (e.g., Gras and Rioux 1965; Kumar Das et al. 1984). The concentration
of dissolved oxygen was too low in tests reported by EG&G Bionomics (1981a).
Douglas et al. (1986) did not observe sufficient mortalities to calculate a
useful LC50.

Data were not used when TBT was a component of a formulation, mixture,
paint, or sediment (Cardarelli 1978; Deschiens and Floch 1970; Laughlin et al.
1982; Maguire and Tkacz 1985; North Carolina Department of Natural Resources
and Community Development 1983; Pope 1981; Quick and Cardarelli 1977; Salazar
and Salazar 1985a,b; Santos et al. 1977; Sherman 1983; Sherman and Hoang 1981;
Sherman and Jackson 1981; Walker 1977; Weisfeld 1970), unless data were
available to show that the toxicity was the same as for TBT alone.

16

Data were not used when the test organisms were infested with tapeworms (e.g., Hnath 1970). Mottley (1978) conducted tests with a mutant form of an alga. Results of tests in which enzymes, excised or homogenized tissue, or cell cultures were exposed to the test material were not used (e.g., Blair et al. 1982). Tests conducted with too few test organisms were not used (e.g., EG&G Bionomics 1976; Good et al. 1979). High control mortalities occurred in tests reported by Salazar and Salazar (Manuscript) and Valkirs et al. (1985). Some data were not used because of problems with the concentration of the test material (e.g., Springborn Bionomics 1984b; Stephenson et al. 1986; Ward et al. 1981). BCFs were not used when the concentration of TBT in the test solution was not measured (Laughlin and French, Manuscript; Laughlin et al. 1986b).

Summary

The acute toxicity values for eight freshwater animal species range from 0.5 μg/L for a hydra to 10.2 μg/L for a mosquito. Chronic toxicity tests have been conducted with two freshwater animals. Reproduction of Daphnia magna was reduced by 0.2 μg/L, but not by 0.1 μg/L, and the acute-chronic ratio was 30.41. Weight of fathead minnows was reduced by 0.45 μg/L, but not by 0.15 μg/L, and the acute-chronic ratio for this species was 10.01. Growth of thirteen species of freshwater algae was inhibited by concentrations ranging from 56.1 to 1,782 μg/L.

Acute values for 19 species of saltwater animals range from 0.61 μg/L for the mysid, Acanthomysis sculpta, to 204.4 μg/L for adult European flat oysters, Ostrea edulis. Acute values for the eleven most sensitive genera, including molluscs, crustaceans, and fishes, differ by less than a factor of 4. Larvae and juveniles appear to be more sensitive than adults. A life-cycle toxicity test has been conducted with the saltwater

17

mysid, Acanthomysis sculpta. The chronic value for A. sculpta was 0.1308 μg/L based on reduced reproduction and the acute-chronic ratio was 4.664.

Bioconcentration factors for three species of bivalve molluscs range from 192.3 for soft parts of the European flat oyster to 11,400 for soft parts of the Pacific oyster, Crassostrea gigas. Imposex, which is the superimposition of male characteristics on female stenoglossan gastropods, occurred among Nucella lapillus exposed to 0.05 μg/L in the laboratory and might occur in field-exposed snails at 0.0024 μg/L. For some species of snails imposex has been associated with reduced reproductive potential and population density, particularly in the vicinity of marinas. Growth or development was reduced at 0.023 μg/L for Crassostrea gigas, 0.019 μg/L for Ostrea edulis, and 0.025 μg/L for Mercenaria mercenaria. A TBT concentration of 0.047 μg/L was lethal to larval C. gigas.

Aquatic Life Advisories

If the measured or estimated ambient concentration of tributyltin (TBT) exceeds 0.026 μg/L in fresh water or 0.010 μg/L in salt water, the discharger, after consultation with an appropriate regulatory agency, should evaluate the available exposure and effect data and complete one or more of the following options within a reasonable period of time:

    a. Obtain additional measurements of the ambient concentration.

    b. Improve the estimate of the ambient concentration.

    c. Obtain additional laboratory and/or field data on the effects of TBT on aquatic organisms and their uses so that a revised, and usually higher, aquatic life advisory concentration or a water quality criterion can be derived.

d. Conduct appropriate toxicity tests on the effluent.

e. Reduce the ambient concentration of TBT to an acceptable level.
After a reasonable period of time, an appropriate regulatory agency should
evaluate all available pertinent data concerning the ambient concentration and
the effects of TBT on aquatic organisms and their uses to determine whether it
is appropriate to take any action, such as modifying the discharge permit.
The analytical method used should distinguish TBT from inorganic tin and from
other organotin compounds (Laughlin et al. 1986a; Lee 1986; Maguire et al.
1984; Mathias et al. 1986; Valkirs et al. 1985b).

Table 1. Acute Toxicity of Tributyltin to Aquatic Animals

Species	Method[a]	Chemical[b]	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 $(\mu g/L)$[c]	Species Mean Acute Value $(\mu g/L)$	Reference
FRESHWATER SPECIES						
Hydra, Hydra sp.	S, M	TBTO (96%)	51.0	0.5	0.5	Brooke et al. 1986
Annelid (9 mg), Lumbriculus variegatus	F, M	TBTO (96%)	51.8	5.4	5.4	Brooke et al. 1986
Cladoceran, Daphnia magna	S, U	TBTO	-	66.3[d]	-	Foster 1981
Cladoceran (adult), Daphnia magna	S, U	TBTC	-	5.26	-	Meador 1986
Cladoceran (<24 hr), Daphnia magna	F, M	TBTO (96%)	51.5	4.3	4.3	Brooke et al. 1986
Amphipod, Gammarus pseudolimnaeus	F, M	TBTO (96%)	51.8	3.7	3.7	Brooke et al. 1986
Mosquito (larva), Culex sp.	S, M	TBTO (96%)	51.5	10.2	10.2	Brooke et al. 1986
Rainbow trout (juvenile), Salmo gairdneri	F, M	TBTO (96%)	50.6	3.9	3.9	Brooke et al. 1986
Fathead minnow (juvenile), Pimephales promelas	F, M	TBTO (96%)	51.5	2.6	2.6	Brooke et al. 1986
Channel catfish (juvenile), Ictalurus punctatus	F, M	TBTO (96%)	51.8	5.5	5.5	Brooke et al. 1986
Bluegill, Lepomis macrochirus	S, U	TBTO	-	227.4[d]	-	Foster 1981

Table 1. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)[c]	Species Mean Acute Value (µg/L)	Reference
			SALTWATER SPECIES			
Polychaete (juvenile), Neanthes arenaceodentata	S, U	TBTO	33-34	6.812	-	Salazar and Salazar, Manuscript
Polychaete (adult), Neanthes arenaceodentata	S, U	TBTO	33-34	21.41[e]	6.812	Salazar and Salazar, Manuscript
Blue mussel (larva), Mytilus edulis	R, -	TBTO	-	2.238	-	Thain 1983
Blue mussel (adult), Mytilus edulis	R, -	TBTO	-	36.98[e]	-	Thain 1983
Blue mussel (adult), Mytilus edulis	S, U	TBTO	33-34	34.06[e]	2.238	Salazar and Salazar, Manuscript
Pacific oyster (larva), Crassostrea gigas	R, -	TBTO	-	1.557	-	Thain 1983
Pacific oyster (adult), Crassostrea gigas	R, -	TBTO	-	282.2[e]	1.557	Thain 1983
Eastern oyster (embryo), Crassostrea virginica	S, U	TBTO (95%)	22	0.8759	-	EG&G Bionomics 1977
Eastern oyster (embryo), Crassostrea virginica	R, U	TBTC	18-22	1.30	-	Roberts, Manuscript
Eastern oyster (embryo), Crassostrea virginica	R, U	TBTC	18-22	0.71	-	Roberts, Manuscript

Table 1. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)[c]	Species Mean Acute Value (µg/L)	Reference
Eastern oyster Crassostrea virginica	R, U	TBTC	18-22	3.96[e]	0.9316	Roberts, Manuscript
European flat oyster (adult), Ostrea edulis	R, -	TBTO	-	204.4	204.4	Thain 1983
Hard clam (post larva), Mercenaria mercenaria	S, U	TBTC	-	0.01466[d]	-	Becerra-Huencho 1984
Hard clam (embryo), Mercenaria mercenaria	R, U	TBTC	18-22	1.13	-	Roberts, Manuscript
Hard clam (larva), Mercenaria mercenaria	R, U	TBTC	18-22	1.65	1.365	Roberts, Manuscript
Copepod (juvenile), Eurytemora affinis	F, M	TBTC	10.6	2.2	2.2	Hall et al., Manuscript
Copepod (adult), Acartia tonsa	R, U	TBTO (95%)	-	0.6326	0.6326	U'ren 1983
Copepod (adult), Nitocra spinipes	S, U	TBTF	7	1.877	-	Linden et al. 1979
Copepod (adult), Nitocra spinipes	S, U	TBTO	7	1.946	1.911	Linden et al. 1979
Mysid (juvenile), Acanthomysis sculpta	R, M	f	-	0.42	-	Davidson et al. 1986a,b
Mysid (juvenile), Acanthomysis sculpta	F, M	f	-	0.61	-	Valkirs et al. 1985a

Table 1. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)[c]	Species Mean Acute Value (µg/L)	Reference
Mysid (adult), Acanthomysis sculpta	F, M	f	-	1.68[e]	0.61	Valkirs et al. 1985a
Mysid (juvenile), Metamysidopsis elongata	S, U	TBTO	33-34	<0.9732	-	Salazar and Salazar, Manuscript
Mysid (subadult), Metamysidopsis elongata	S, U	TBTO	33-34	1.946[e]	-	Salazar and Salazar, Manuscript
Mysid (adult), Metamysidopsis elongata	S, U	TBTO	33-34	6.812[e]	-	Salazar and Salazar, Manuscript
Mysid (adult), Metamysidopsis elongata	S, U	TBTO	33-34	2.433[e]	<0.9732	Salazar and Salazar, Manuscript
Amphipod (adult), Orchestia traskiana	R, M	TBTO	30	>14.60[g]	-	Laughlin et al. 1982
Amphipod (adult), Orchestia traskiana	R, M	TBTF	30	>14.08[g]	>14.60	Laughlin et al. 1982
American lobster (larva), Homarus americanus	R, U	TBTO	32	1.745[g]	1.745	Laughlin and French 1980
Shore crab (larva), Carcinus maenas	R, -	TBTO	-	9.732	9.732	Thain 1983
Mud crab (larva), Rhithropanopeus harrisii	R, U	TBTS	15	34.90[g]	-	Laughlin et al. 1983
Mud crab (larva), Rhithropanopeus harrisii	R, U	TBTO	15	>24.3[g]	34.90	Laughlin et al. 1983

23

Table 1. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 $(\mu g/L)$[c]	Species Mean Acute Value $(\mu g/L)$	Reference
Shore crab (larva), Hemigrapsus nudus	R, U	TBTO	32	83.28[g]	83.28	Laughlin and French 1980
Sheepshead minnow (juvenile), Cyprinodon variegatus	S, U	TBTO	20	16.54	-	EG&G Bionomics 1979
Sheepshead minnow (juvenile), Cyprinodon variegatus	S, U	TBTO	20	16.54	-	EG&G Bionomics 1979
Sheepshead minnow (juvenile), Cyprinodon variegatus	S, U	TBTO	20	12.65	-	EG&G Bionomics 1979
Sheepshead minnow (33-49 mm), Cyprinodon variegatus	F, M	TBTO	28-32	2.315[g]	2.315	EG&G Bionomics 1981d
Mummichog (adult), Fundulus heteroclitus	S, U	TBTO (95%)	25	23.36	23.36	EG&G Bionomics 1976
Chinook salmon (juvenile), Oncorhynchus tshawytscha	S, M	TBTO	28	1.460	1.460	Short and Thrower 1986b

[a] S = static; R = renewal; F = flow-through; M = measured; U = unmeasured.

[b] TBTC = tributyltin chloride; TBTF = tributyltin fluoride; TBTO = tributyltin oxide; TBTS = tributyltin sulfide. Percent purity is given in parentheses when available.

[c] Concentration of the tributyltin cation, not the chemical. If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 95%.

24

Table 1. (continued)

[d] Value not used in determination of Species Mean Acute Value (see text).

[e] Value not used in determination of Species Mean Acute Value because data are available for a more sensitive life stage.

[f] The test organisms were exposed to leachate from panels coated with antifouling paint containing a tributyltin polymer and cuprous oxide. Concentrations of TBT were measured and Davidson et al. (1986a) demonstrated that TBT in the leachate had the same toxicity as TBT alone.

[g] LC50 or EC50 calculated or interpolated graphically based on the authors' data.

Table 2. Chronic Toxicity of Tributyltin to Aquatic Animals

Species	Test[a]	Chemical[b]	Hardness (mg/L as CaCO$_3$)	Limits (μg/L)[c]	Chronic Value (μg/L)	Reference
FRESHWATER SPECIES						
Cladoceran, Daphnia magna	LC	TBTO (96%)	51.5	0.1-0.2	0.1414	Brooke et al. 1986
Fathead minnow, Pimephales promelas	ELS	TBTO (96%)	51.5	0.15-0.45	0.2598	Brooke et al. 1986
SALTWATER SPECIES						
Mysid, Acanthomysis sculpta	LC	d	-	0.09-0.19	0.1308	Davidson et al. 1986a,b

[a] LC = life-cycle or partial life-cycle; ELS = early life-stage.

[b] TBTO = tributyltin oxide. Percent purity is given in parentheses when available.

[c] Measured concentrations of the tributyltin cation.

[d] The test organisms were exposed to leachate from panels coated with antifouling paint containing a tributyltin polymer and cuprous oxide. Concentrations of TBT were measured and Davidson et al. (1986a) demonstrated that the TBT in the leachate had the same toxicity as TBT alone.

Table 2. (continued)

Species	Hardness (mg/L as CaCO$_3$)	Acute-Chronic Ratio		
		Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Cladoceran, *Daphnia magna*	51.5	4.3	0.1414	30.41
Fathead minnow, *Pimephales promelas*	51.5	2.6	0.2598	10.01
Mysid, *Acanthomysis sculpta*	-	0.61[a]	0.1308	4.664

[a] Reported by Valkirs et al. (1985a).

Table 3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank[a]	Genus Mean Acute Value (μg/L)	Species	Species Mean Acute Value (μg/L)[b]	Species Mean Acute-Chronic Ratio[c]
		FRESHWATER SPECIES		
8	10.2	Mosquito, Culex sp.	10.2	-
7	5.5	Channel catfish, Ictalurus punctatus	5.5	-
6	5.4	Annelid, Lumbriculus variegatus	5.4	-
5	4.3	Cladoceran, Daphnia magna	4.3	30.41
4	3.9	Rainbow trout, Salmo gairdneri	3.9	-
3	3.7	Amphipod, Gammarus pseudolimnaeus	3.7	-
2	2.6	Fathead minnow, Pimephales promelas	2.6	10.01
1	0.5	Hydra, Hydra sp.	0.5	-

Table 3. (continued)

Rank[a]	Genus Mean Acute Value (μg/L)	Species	Species Mean Acute Value (μg/L)[b]	Species Mean Acute-Chronic Ratio[c]
		SALTWATER SPECIES		
18	204.4	European flat oyster, Ostrea edulis	204.4	-
17	83.28	Shore crab, Hemigrapsus nudus	83.28	-
16	34.90	Mud crab, Rhithropanopeus harrisii	34.90	-
15	23.36	Mummichog, Fundulus heteroclitus	23.36	-
14	>14.60	Amphipod, Orchestia traskiana	>14.60	-
13	9.732	Shore crab, Carcinus maenas	9.732	-
12	6.812	Polychaete, Neanthes arenaceodentata	6.812	-
11	2.315	Sheepshead minnow, Cyprinodon variegatus	2.315	-
10	2.238	Blue mussel, Mytilus edulis	2.238	-
9	2.2	Copepod, Eurytemora affinis	2.2	-

Table 3. (continued)

Rank[a]	Genus Mean Acute Value (μg/L)	Species	Species Mean Acute Value (μg/L)[b]	Species Mean Acute-Chronic Ratio[c]
8	1.911	Copepod, Nitocra spinipes	1.911	-
7	1.745	American lobster, Homarus americanus	1.745	-
6	1.460	Chinook salmon, Oncorhynchus tshawytscha	1.460	-
5	1.365	Hard clam, Mercenaria mercenaria	1.365	-
4	1.204	Pacific oyster, Crassostrea gigas	1.557	-
		Eastern oyster, Crassostrea virginica	0.9316	-
3	0.9732	Mysid, Metamysidopsis elongata	<0.9732[d]	-
2	0.6326	Copepod, Acartia tonsa	0.6326	-
1	0.61	Mysid, Acanthomysis sculpta	0.61	4.664

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

[b] From Table 1.

[c] From Table 2.

[d] This was used as the Genus Mean Acute Value in the calculation of the Final Acute Value. This was the lowest concentration used in the toxicity test and it killed 63% of the exposed mysids.

Table 3. (continued)

<u>Fresh water</u>

Final Acute Value = 0.2972 μg/L

Final Acute-Chronic Ratio = 11.24 (see text)

Final Chronic Value = (0.2972 μg/L) / 11.24 = 0.02644 μg/L

<u>Salt water</u>

Final Acute Value = 0.5313 μg/L

Final Acute-Chronic Ratio = 11.24 (see text)

Final Chronic Value = (0.5313 μg/L) / 11.24 = 0.04727 μg/L

Final Chronic Value = 0.010 μg/L (lowered to protect molluscs; see text)

Table 4. Toxicity of Tributyltin to Aquatic Plants

Species	Chemical[a]	Hardness (mg/L as) CaCO_3	Duration (days)	Effect	Concentration (µg/L)[b]	Reference
			FRESHWATER SPECIES			
Alga, _Bumilleriopsis filiformis_	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984
Alga, _Klebsormidium marinum_	TBTC	-	14	No growth	222.8	Blanck 1986; Blanck et al. 1984
Alga, _Monodus subterraneus_	TBTC	-	14	No growth	1,782.2	Blanck 1986; Blanck et al. 1984
Alga, _Raphidonema longiseta_	TBTC	-	14	No growth	56.1	Blanck 1986; Blanck et al. 1984
Alga, _Tribonema aequale_	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984
Blue-green alga, _Oscillatoria_ sp.	TBTC	-	14	No growth	222.8	Blanck 1986; Blanck et al. 1984
Blue-green alga, _Synechococcus leopoliensis_	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984
Green alga, _Chlamydomonas dysosmas_	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984
Green alga, _Chlorella emersonii_	TBTC	-	14	No growth	445.5	Blanck 1986; Blanck et al. 1984
Green alga, _Kirchneriella contorta_	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984

32

Table 4. (continued)

Species	Chemical[a]	Hardness (mg/L as CaCO₃)	Duration (days)	Effect	Concentration (µg/L)[b]	Reference
Green alga, Monoraphidium pusillum	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984
Green alga, Scenedesmus obtusiusculus	TBTC	-	14	No growth	445.5	Blanck 1986; Blanck et al. 1984
Green alga, Selenastrum capricornutum	TBTC	-	14	No growth	111.4	Blanck 1986; Blanck et al. 1984

<div align="center">SALTWATER SPECIES</div>

Species	Chemical[a]	Hardness (mg/L as CaCO₃)	Duration (days)	Effect	Concentration (µg/L)[b]	Reference
Diatom, Skeletonema costatum	TBTO	-	5	Algistatic algicidal	0.9732-17.52 >17.52	Thain 1983
Diatom, Skeletonema costatum	TBTO (BioMet Red)	30[c]	14	EC50 (dry cell weight)	>0.1216; <0.2433	EG&G Bionomics 1981c
Diatom, Skeletonema costatum	TBTO (alkyl source)	30[c]	14	EC50 (dry cell weight)	0.06228	EG&G Bionomics 1981c

[a] TBTC = tributyltin chloride; TBTO = tributyltin oxide. Percent purity is given in parentheses when available.

[b] Concentration of the tributyltin cation, not the chemical. If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 95%.

[c] Salinity (g/kg), not hardness.

33

Table 5. Bioaccumulation of Tributyltin by Aquatic Organisms

Species	Chemical[a]	Salinity (g/kg)	Concentration in Water (ug/L)[b]	Duration (days)	Tissue	BCF or BAF[c]	Reference
FRESHWATER SPECIES							
Green alga, Ankistrodesmus falcatus	TBTO	-	5.2	7	-	300	Maguire et al. 1984
			4.7	14	-	253	
			2.1	21	-	448	
			1.5	28	-	467	
SALTWATER SPECIES							
Blue mussel (spat), Mytilus edulis	d	28.5-34.2	0.24	45	Soft parts	6,833[e]	Thain and Waldock 1985; Thain 1986
Pacific oyster, Crossostrea gigas	TBTO	28-31.5	1.216	21	Soft parts	1,874[e]	Waldock et al. 1983
Pacific oyster, Crossostrea gigas	TBTO	28-31.5	0.1460	21	Soft parts	6,047[e]	Waldock et al. 1983
Pacific oyster, Crossostrea gigas	d	28.5-34.2	0.24	45	Soft parts	7,292[e]	Thain and Waldock 1985; Thain 1986
Pacific oyster, Crossostrea gigas	TBTO	29-32	1.557	56	Soft parts	2,300	Waldock and Thain 1983
Pacific oyster, Crossostrea gigas	TBTO	29-32	0.1460	56	Soft parts	11,400	Waldock and Thain 1983
European flat oyster, Ostrea edulis	TBTO	28-31.5	1.216	21	Soft parts	960[e]	Waldock et al. 1983

34

Table 5. (continued)

Species	Chemical[a]	Salinity (g/kg)	Concentration in Water (µg/L)[b]	Duration (days)	Tissue	BCF or BAF[c]	Reference
European flat oyster, _Ostrea edulis_	TBTO	28-34.2	0.24	75	Soft parts	875[e]	Waldock et al. 1983;
European flat oyster, _Ostrea edulis_	TBTO	28-34.2	2.62	75	Soft parts	397[e]	Thain 1986
European flat oyster, _Ostrea edulis_	[d]	28.5-34.2	0.24	45	Soft parts	1,167[e]	Thain and Waldock 1985; Thain 1986
European flat oyster, _Ostrea edulis_	[d]	28.5-34.2	2.62	45	Soft parts	192.3[e]	Thain and Waldock 1985; Thain 1986

[a] TBTO = tributyltin oxide. Percent purity is given in parentheses when available.

[b] Measured concentration of the tributyltin cation.

[c] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of the tributyltin cation in water and in tissue.

[d] Test organisms were exposed to leachate from panels coated with antifouling paint containing tributyltin.

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

[f] Steady-state not reached.

35

Table 6. Other Data on Effects of Tributyltin on Aquatic Organisms

Species	Chemical[a]	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration $(\mu g/L)$[b]	Reference
			FRESHWATER SPECIES			
Algae, Natural assemblge	-	-	4 hr	EC50 (production)	5	Wong et al. 1982
Blue-green alga, Anabaena flos-aquae	-	-	4 hr	EC50 (reproduction)	13	Wong et al. 1982
Green alga, Ankistrodesmus falcatus	-	-	4 hr	EC50 (production) (reproduction)	20 5	Wong et al. 1982
Green alga, Scenedesmus quadricauda	-	-	4 hr	EC50 (production)	16	Wong et al. 1982
Clam (larva), Corbicula fluminea	TBTO	-	24 hr	EC50	1,990	Foster 1981
Cladoceran, Daphnia magna	-	-	24 hr	LC50	3	Polster and Halacha 1972
Cladoceran (<24 hr), Daphnia magna	TBTC	200	24 hr	EC50 (mobility)	11.6	Vighi and Calamari 1985
Cladoceran (<24 hr), Daphnia magna	TBTO	200	24 hr	EC50 (mobility)	13.6	Vighi and Calamari 1985
Cladoceran (adult), Daphnia magna	TBTC	-	8 days	Altered phototaxis	0.45	Meador 1986
Rainbow trout (yearling), Salmo gairdneri	TBTO	-	24 hr 48 hr	LC50	25.2 18.9	Alabaster 1969

Table 6. (continued)

Species	Chemical[a]	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration $(\mu g/L)$[b]	Reference
Rainbow trout, Salmo gairdneri	TBTO	-	24 hr	EC50 (rheotaxis)	30.8	Chliamovitch and Kuhn 1977
Rainbow trout (embryo, larva), Salmo gairdneri	TBTC	94-102	110 days	20% reduction in growth	0.18	Seinen et al. 1981
				23% reduction in growth; 6.6% mortality	0.89	
				100% mortality	4.46	
Frog (embryo, larva), Rana temporaria	TBTO	-	5 days	LC40	28.4	Laughlin and Linden 1982
	TBTF	-	5 days	LC50	28.2	
	TBTO	-	5 days	Loss of body water	28.4	
	TBTF	-	5 days	Loss of body water	28.2	

37

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
			SALTWATER SPECIES			
Natural microbial populations	TBTC	2 or 17	1 hr	Significant decrease in metabolism of nutrient substrates	4.454	Jonas et al. 1984
Natural microbial populations	TBTC	2 or 17	1 hr (incubated 10 days)	50% mortality	89.07	Jonas et al. 1984
Green alga, _Dunaliella_ sp.	TBTO	-	72 hr	Approx. EC50 (growth)	1.460	Salazar 1985
Green alga, _Dunaliella_ sp.	TBTO	-	72 hr	100% mortality	2.920	Salazar 1985
Diatom, _Phaeodactylum tricornutum_	TBTO	-	72 hr	No effect on growth	1.460-5.839	Salazar 1985
Diatom, _Skeletonema costatum_	TBTA	30	72 hr	EC50 (population growth)	0.3097	Walsh et al. 1985
Diatom, _Skeletonema costatum_	TBTA	30	72 hr	LC50	12.65	Walsh et al. 1985

38

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (μg/L)[b]	Reference
Diatom, Skeletonema costatum	TBTO	30	72 hr	EC50 (population growth)	0.3212	Walsh et al. 1985
Diatom, Skeletonema costatum	TBTO	30	72 hr	LC50	13.82	Walsh et al. 1985
Diatom, Skeletonema costatum	TBTC	30	72 hr	EC50 (population growth)	0.3207	Walsh et al. 1985
Diatom, Skeletonema costatum	TBTC	30	72 hr	LC50	10.24	Walsh et al. 1985
Diatom, Skeletonema costatum	TBTF	30	72 hr	EC50 (population growth)	>0.2346, <0.4693	Walsh et al. 1985
Diatom, Skeletonema costatum	TBTF	30	72 hr	LC50	11.17	Walsh et al. 1985
Diatom, Thalassiosira pseudonana	TBTA	30	72 hr	EC50 (population growth)	1.101	Walsh et al. 1985
Diatom, Thalassiosira pseudonana	TBTO	30	72 hr	EC50 (population growth)	1.002	Walsh et al. 1985

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Dinoflagellate, Gymnodinium splendens	TBTO	–	72 hr	100% mortality	1.460	Salazar 1985
Dogwhelk (adult), Nucella lapillus	c	–	120 days	41% Imposex (superimposition of male anatomical characteristics on females)	0.05	Bryan et al. 1986
Mud snail (adult), Nassarius obsoletus	TBTO	23	35-75 days	Imposex	–	Smith 1981
Blue mussel (spat), Mytilus edulis	c	28.5-34.2	45 days	Significant reduction in growth; no mortality	0.24	Thain and Waldock 1985; Thain 1986
Blue mussel (spat), Mytilus edulis	c	28.5-34.2	45 days	100% mortality	2.6	Thain and Waldock 1985; Thain 1986
Blue mussel (larva), Mytilus edulis	TBTO	33	15 days	51% mortality; reduced growth	0.0973	Beaumont and Budd 1984
Blue mussel (juvenile), Mytilus edulis	TBTO	33.7	7 days	Significant reduction in growth	0.3893	Stromgren and Bongard 1987

40

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (μg/L)[b]	Reference
Blue mussel (2.5 to 4.1 cm), Mytilus edulis	c	−	66 days	LC50	0.97	Valkirs et al. 1985a,1987
Blue mussel (2.5 to 4.1 cm), Mytilus edulis	c	−	66 days	Significant decrease in shell growth	0.31	Valkirs et al. 1985a
Pacific oyster (spat), Crassostrea gigas	c	28.5-34.2	45 days	40% mortality; reduced growth	0.24	Thain and Waldock 1985; Thain 1986
Pacific oyster (spat), Crassostrea gigas	c	28.5-34.2	45 days	90% mortality	2.6	Thain and Waldock 1985
Pacific oyster (spat), Crassostrea gigas	TBTO	29-32	56 days	No growth	1.557	Waldock and Thain 1983
Pacific oyster (spat), Crassostrea gigas	TBTO	29-32	56 days	Reduced growth	0.1460	Waldock and Thain 1983
Pacific oyster (larva), Crassostrea gigas	c	−	30 days	100% mortality	2.0	Alzieu et al. 1980
Pacific oyster (larva), Crassostrea gigas	c	−	113 days	30 % mortality and abnormal development	0.2	Alzieu et al. 1980
Pacific oyster (larva), Crassostrea gigas	TBTF	18-21	21 days	Reduced number of normally developed larvae and setting of spat	0.02346	Springborn Bionomics 1984a

41

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Pacific oyster (larva), Crassostrea gigas	TBTF	18-21	15 days	100% mortality	0.04692	Springborn Bionomics 1984a
Pacific oyster (embryo), Crassostrea gigas	TBTA	28	24 hr	Abnormal development; 30-40% mortality	4.304	His and Robert 1980
Pacific oyster (embryo), Crassostrea gigas	TBTA	-	24 hr	Abnormal development	0.8604	Robert and His 1981
Pacific oyster (larva), Crassostrea gigas	TBTA	-	24 hr	Abnormal development	0.9-4	Robert and His 1981
Pacific oyster (larva), Crassostrea gigas	TBTA	-	48 hr	100% mortality	2.581	Robert and His 1981
Eastern oyster (2.7-5.3 cm), Crassostrea virginica	d	-	67 days	Decrease in condition index (body weight)	0.73	Valkirs et al. 1985a
Eastern oyster (2.7-5.3 cm), Crassostrea virginica	d	-	67 days	No effect on survival	1.89	Valkirs et al. 1985a
Eastern oyster (adult), Crassostrea virginica	c	33-36	57 days	Decrease in condition index	0.1	Henderson 1986
Eastern oyster (adult), Crassostrea virginica	c	33-36	30 days	LC50	2.5	Henderson 1986
Eastern oyster (embryo), Crassostrea virginica	TBTC	18-22	48 hr	Abnormal shell development	0.77	Roberts, Manuscript
European flat oyster (spat), Ostrea edulis	TBTO	30	20 days	Significant reduction in growth	0.01946	Thain and Waldock 1985

42

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (μg/L)[b]	Reference
European flat oyster (spat), Ostrea edulis	c	28.5-34.2	45 days	Decreased growth	0.2392	Thain and Waldock 1985; Thain 1986
European flat oyster (spat), Ostrea edulis	c	28.5-34.2	45 days	70% mortality	2.6	Thain and Waldock 1985; Thain 1986
European flat oyster (adult), Ostrea edulis	c	28-34	75 days	Complete inhibition of larval production	0.24	Thain 1986
European flat oyster (adult), Ostrea edulis	c	28-34	75 days	Retardation of sex change from male to female	0.24	Thain 1986
European flat oyster (adult), Ostrea edulis	c	28-34	75 days	Prevented gonadal development	2.6	Thain 1986
Hard clam (post larva), Mercenaria mercenaria	TBTC (95%)	-	96 hr	Inhibited swimming behavior	0.0007330	Becerra-Huencho 1984
Hard clam (post larva), Mercenaria mercenaria	TBTC (95%)	-	96 hr	Reduced number of animals developing a foot	0.002922	Becerra-Huencho 1984
Hard clam (embryo, larva), Mercenaria mercenaria	TBTO	-	14 days	Reduced growth	0.025	Laughlin et al. 1987

43

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Hard clam (larva), Mercenaria mercenaria	TBTO	-	8 days	Approx. 35% dead	0.6	Laughlin et al. 1987
Hard clam (post larva), Mercenaria mercenaria	TBTO	-	25 days	100% dead Percent survival better than controls	10. 7.5	Laughlin et al. 1987
Hard clam (larva), Mercenaria mercenaria	TBTC	18-22	48 hr	Delayed development	0.77	Roberts, Manuscript
Clam (adult), Protothaca stamina	TBTO	33-34	96 hr	100% survival	≥2.920	Salazar and Salazar, Manuscript
Copepod, Eurytemora affinis	TBTC	10.3	13 days	Reduced survival of neonates and adults	0.088	Hall et al., Manuscript
Copepod, Eurytemora affinis	TBTC	14.6	13 days	Reduced survival of neonates	0.224	Hall et al., Manuscript
Copepod, Acartia tonsa	TBTO	-	144 hr	EC50	0.3893	U'ren 1983
Amphipod (larva, juvenile), Gammarus oceanus	TBTO	7	8 wk	100% mortality	2.920	Laughlin et al. 1984b
Amphipod (larva, juvenile), Gammarus oceanus	TBTF	7	8 wk	100% mortality	2.816	Laughlin et al. 1984b
Amphipod (larva, juvenile), Gammarus oceanus	TBTO	7	8 wk	Reduced survival and growth	0.2920	Laughlin et al. 1984b
Amphipod (larva, juvenile), Gammarus oceanus	TBTF	7	8 wk	Reduced survival and increased growth	0.2816	Laughlin et al. 1984b

44

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Amphipod (adult), Orchestia traskiana	TBTO	30	9 days	Approx. 80% mortality	9.732	Laughlin et al. 1982
Amphipod (adult), Orchestia traskiana	TBTF	30	9 days	Approx. 90% mortality	9.732	Laughlin et al. 1982
Grass shrimp, Palaemonetes pugio	TBTO (95%)	9.9-11.2	20 min	No avoidance	30.	Pinkney et al. 1985
Mud crab (larva), Rhithropanopeus harrisii	TBTO	15	15 days	Reduced developmental rate and growth	14.60	Laughlin et al. 1983
Mud crab (larva), Rhithropanopeus harrisii	TBTS	15	15 days	Reduced developmental rate and growth	18.95	Laughlin et al. 1983
Mud crab (larva), Rhithropanopeus harrisii	TBTO	15	15 days	63% mortality	>24.33	Laughlin et al. 1983
Mud crab (larva), Rhithropanopeus harrisii	TBTS	15	15 days	74% mortality	28.43	Laughlin et al. 1983
Mud crab, Rhithropanopeus harrisii	TBTO	15	6 days	BCF=24 for carapace	5.937	Evans and Laughlin 1984
Mud crab, Rhithropanopeus harrisii	TBTO	15	6 days	BCF=6 for hepato-pancreas	5.937	Evans and Laughlin 1984
Mud crab, Rhithropanopeus harrisii	TBTO	15	6 days	BCF=0.6 for testes	5.937	Evans and Laughlin 1984

45

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (μg/L)[b]	Reference
Mud crab, Rhithropanopeus harrisii	TBTO	15	6 days	BCF=41 for gill tissue	5.937	Evans and Laughlin 1984
Mud crab, Rhithropanopeus harrisii	TBTO	15	6 days	BCF=1.5 for chelae muscle	5.937	Evans and Laughlin 1984
Fiddler crab, Uca pugilator	TBTO	25	≤24 days	Retarded limb regeneration and molting	0.5	Weis et al. 1987
Atlantic menhaden (juvenile), Brevoortia tyrannus	TBTO	9-11	-	Avoidance	5.437	Hall et al. 1984
Chinook salmon (adult), Oncorhynchus tshawytscha	TBTO	28	96 hr	BCF=4300 for liver	1.49	Short and Thrower 1986a,c
Chinook salmon (adult), Oncorhynchus tshawytscha	TBTO	28	96 hr	BCF=1300 for brain	1.49	Short and Thrower 1986a,c
Chinook salmon (adult), Oncorhynchus tshawytscha	TBTO	28	96 hr	BCF=200 for muscle	1.49	Short and Thrower 1986a,c
Mummichog, Fundulus heteroclitus	TBTO (95%)	9.9-11.2	20 min	Avoidance	3.7	Pinkney et al. 1985
California grunion (gamete through embryo), Leuresthes tenuis	c	-	10 days	Significantly enhanced growth and hatching success	0.14-1.72	Newton et al. 1985
California grunion (gamete through embryo), Leuresthes tenuis	c	-	10 days	50% reduction in hatching success	74	Newton et al. 1985

46

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
California grunion (embryo), _Leuresthes tenuis_	c	-	10 days	No adverse effect on hatching success or growth	0.14-1.72	Newton et al. 1985
California grunion (larva), _Leuresthes tenuis_	c	-	7 days	Survival increased as concentration increased	0.14-1.72	Newton et al. 1985
Striped bass (juvenile), _Morone saxatilis_	TBTO (95%)	9-11	-	Avoidance	24.9	Hall et al. 1984
Speckled sanddab (adult), _Chitharichthys stigmaeus_	TBTO	33-34	96 hr	LC50	18.5	Salazar and Salazar, Manuscript

47

[a] TBTA = tributyltin acetate; TBTC = tributyltin chloride; TBTF = tributyltin fluoride; TBTO = tributyltin oxide; TBTS = tributyltin sulfide. Percent purity is given in parentheses when available.

[b] Concentration of the tributyltin cation, not the chemical. If the concentrations were not measured and the published results were not reported to be adjusted for purity, the published results were multiplied by the purity if it was reported to be less than 95%.

[c] The test organisms were exposed to leachate from panels coated with antifouling paint containing tributyltin.

[d] The test organisms were exposed to leachate from panels coated with antifouling paint containing a tributyltin polymer and cuprous oxide. Concentrations of TBT were measured and Davidson et al. (1986a) demonstrated that the TBT in the leachate had the same toxicity as TBT alone.

REFERENCES

Alabaster, J.S. 1969. Survival of fish in 164 herbicides, insecticides, fungicides, wetting agents and miscellaneous substances. Int. Pest Control 11:29-35.

Allen, A.J., B.M. Quitter and C.M. Radick. 1980. The biocidal mechanisms of controlled release bis(tri-n-butyltin) oxide in *Biomphalaria glabrata*. In: Controlled release of bioactive materials. Baker, R. (Ed.). Academic Press, New York, NY. pp. 399-413.

Alzieu, C. 1986. The detrimental effects on oyster culture in France - evolution since antifouling paint regulation. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1130-1134.

Alzieu, C., Y. Thibaud, M. Heral and B. Boutier. 1980. Evaluation of the risks of using antifouling paints near oyster zones. Rev. Trav. Inst. Peches Marit. 44:301-348.

Barug, D. 1981. Microbial degradation of bis(tributyltin) oxide. Chemosphere 10:1145-1154.

Beaumont, A.R. and M.D. Budd. 1984. High mortality of the larvae of the common mussel at low concentrations of tributyltin. Mar. Pollut. Bull. 15:402-405.

Becerra-Huencho, R.M. 1984. The effect of organotin and copper sulfate on the late development and presettlement behavior of the hard clam *Mercenaria mercenaria*. Master's thesis. University of Maryland, College Park, MD.

Blair, W.R., G.J. Olson, F.E. Brinckman and W.P. Iverson. 1982. Accumulation and fate of tri-n-butyltin cation in estuarine bacteria. Microb. Ecol. 8:241-251.

Blanck, H. 1986. University of Goteborg, Goteborg, Sweden. (Memorandum to D.J. Call, Center for Lake Superior Enviromental Studies, University of Wisconsin-Superior, Superior, WI. March 11.)

Blanck, H., G. Wallin and S.A. Wangberg. 1984. Species-dependent variation in algal sensitivity to chemical compounds. Ecotoxicol. Environ. Saf. 8:339-351.

Brooke, L.T., D.J. Call, S.H. Poirier, T.P. Markee, C.A. Lindberg, D.J. McCauley and P.G. Simonson. 1986. Acute toxicity and chronic effects of bis(tri-n-butyltin) oxide to several species of freshwater organisms. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, WI.

Bryan, G.W., P.E. Gibbs, L.G. Hummerstone and G.R. Burt. 1986. The decline of the gastropod *Nucella lapillus* around south-west England: Evidence for the effect of tributyltin from antifouling paints. J. Mar. Biol. Assoc. U. K. 66:611-640.

Camey, T. and E. Paulini. 1964. Molluscicide activity of some organotin compounds. Rev. Bras. Malariol. Doencas Trop. 16:487-491.

49

Cardarelli, N.F. 1978. Controlled release organotins as mosquito larvicides. Mosq. News 38:328-333.

Cardarelli, N.F. and W. Evans. 1980. Chemodynamics and environmental toxicology of controlled release organotin molluscicides. In: Controlled release of bioactive materials. Baker, R. (Ed.). Academic Press, New York, NY. pp. 357-385.

Cardwell, R.D. and A.W. Sheldon. 1986. A risk assessment concerning the fate and effects of tributyltins in the aquatic environment. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1117-1129.

Cardwell, R.D. and P.A. Vogue. 1986. Provisional estimates of water quality criteria for the protection of aquatic life and their uses: Tributyltin compounds. Report by Envirosphere Company, Bellevue, WA., to M&T Chemicals, Woodbridge, NJ.

Champ, M.A. 1986. Organotin symposium: Introduction and overview. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC.

Chau, Y.K. 1986. Occurrence and speciation of organometallic compounds in freshwater systems. Sci. Total Environ. 49:305-323.

Chau, Y.K., R.J. Maguire and P.T. Wong. 1983. Alkyltin compounds in the aquatic environment. In: Proceedings of the ninth annual aquatic toxicity

workshop. Mckay, W.C. (Ed.). Canadian Technical Report of Fisheries and Aquatic Sciences No. 1163. Department of Fisheries and Oceans, Ottawa, Ontario, Canada. p. 204.

Chliamovitch, Y.P. and C. Kuhn. 1977. Behavior, haemotological and histological studies on acute toxicity of bis(tri-n-butyltin) oxide on _Salmo gairdneri_ Richardson and _Tilapia rendalli_ Boulenger. J. Fish Biol. 10:575-585.

Cleary, J.J. and A.R.D. Stebbing. 1985. Organotin and total tin in coastal water of southwest England. Mar. Pollut. Bull. 16:350-355.

Corbin, H.B. 1976. The solubilities of bis(tributyltin) oxide (TBTO), tributyltin fluoride (TBTF), triphenyltin hydroxide (TPTH), triphenyltin fluoride (TPTF), and tricyclohexyltin hydroxide (TCTH) in water as functions of temperature and pH value. Research and Development Technical Memorandum R-1145-M. M&T Chemicals Inc., Rahway, NJ.

Danil'chenko, O. 1982. A comparison of the reaction of fish embryos and prolarvae to certain natural factors and synthesized compounds. J. Ichthyol. (Engl. Transl. Vopr. Ikhtiol.) 22(1):123-134.

Danil'chenko, O. and N.C. Buzinova. 1982. Effect of pollution on the mollusc _Lymnaea stagnalis_. I. Survival, reproduction and embryonic development. Biol. Nauki 25:61-69.

Davidson, B.M., A.O. Valkirs and P.F. Seligman. 1986a. Acute and chronic effects of tributyltin on the mysid _Acanthomysis sculpta_ (Crustacea,

Mysidacea). NOSC-TR-1116 or AD-A175-294-8. National Technical Information Service, Springfield, VA.

Davidson, B.M., A.O. Valkirs and P.F. Seligman. 1986b. Acute and chronic effects of tributyltin on the mysid Acanthomysis sculpta (Crustacea, Mysidacea). In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1219-1225.

de la Court, F.H. 1980. The value of tributyltin fluoride as a toxicant in antifouling formulations. J. Col. Chem. Assoc. 63:465-473.

Deschiens, R. 1968. Control of infectious microorganisms with chemical molluscicides. C. R. Hebd. Seances Acad. Sci. 266D:1860-1861.

Deschiens. R. and H.A. Floch. 1968. Comparison of 6 chemical molluscicides as to their control of bilharziasis. Conclusions. Bull. Soc. Pathol. Exot. 61:640-650.

Deschiens, R. and H.A. Floch. 1970. Molluscicidal use of polyethylene impregnated with tributyltin oxide. Bull. Soc. Pathol. Exot. 63:71-78.

Deschiens, R., H. Floch and T. Floch. 1964. The molluscicidal properties of tributyltin oxide and acetate for prophylaxis of bilharziasis. Bull. Soc. Pathol. Exot. 57:454-465.

Deschiens, R., H. Brottes and L. Mvogo. 1966a. Field application in Cameron of the molluscicide tributyltin oxide to control bilharziasis. Bull. Soc. Pathol. Exot. 59:968-973.

Deschiens, R., H. Brottes and L. Mvogo. 1966b. Effectiveness of field applications of the molluscicide tributyltin oxide (in the control of bilharziasis). Bull. Soc. Pathol. Exot. 59:231-234.

de Sousa, C.P. and E. Paulini. 1970. Absorption of molluscicides by calcium carbonate. Rev. Bras. Malariol. Doencas Trop. 21:799-818.

Douglas, M.T., D.O. Chanter, I.B. Pell and G.M. Burney. 1986. A proposal for the reduction of animal numbers required for the acute toxicity of fish test (LC50 determination). Aquat. Toxicol. 8:243-249.

Durchon, M. 1982. Experimental activation of the neuroendocrine mechanism governing the morphogenesis of the penis in the females of Ocenebra erinacea (a dioecious prosobranch mollusc) by a marine pollutant (tributyltin). C. R. Seances Acad. Sci. 295(III):627-630.

EG&G Bionomics. 1976. Acute toxicity of tri-n-butyltin oxide to channel catfish (Ictalurus punctatus), the fresh water clam (Elliptio complanatus), the common mummichog (Fundulus heteroclitus) and the American oyster (Crassostrea virginica). Final Report to M&T Chemical Co., Rahway, NJ. EPA Acc. No. 136470.

EG&G Bionomics. 1977. Toxicity of tri-n-butyltin oxide (TBTO) to embryos of eastern oysters (Crassostrea virginica). Final Report to M&T Chemical Co., Rahway, NJ. EPA Acc. No. 114085.

EG&G Bionomics. 1979. Acute toxicity of three samples of TBTO (tributyltin oxide) to juvenile sheepshead minnows (<u>Cyprinodon variegatus</u>). Report L14-500 to M&T Chemicals Inc., Rahway, NJ.

EG&G Bionomics. 1981a. Comparative toxicity of tri-butyltin oxide (TBTO) produced by two different chemical processes to pink shrimp (<u>Penaeus duorarum</u>). Report BP-81-4-55 to M&T Chemicals Inc., Rahway, NJ.

EG&G Bionomics. 1981b. Acute toxicity of BioMet 204 Red to mysid shrimp (<u>Mysidopsis bahia</u>). Report BP-81-2-15 to M&T Chemicals Inc., Rahway, NJ.

EG&G Bionomics. 1981c. Comparative toxicity of tri-n-butyltin oxide (TBTO) produced by two different chemical processes to the marine alga <u>Skeletonema costatum</u>. Report BP-81-6-109 to M&T Chemicals Inc., Rahway, NJ

EG&G Bionomics. 1981d. Unpublished laboratory data on acute toxicity of tributyltin to sheepshead minnow, <u>Cyprinodon variegatus</u>. Pensacola, FL.

Envirosphere Company. 1986. A risk assessment concerning potential aquatic environmental and public health consequences associated with the use of tributyltin compounds in antifouling coatings. Vol. 1 and 2. Prepared for M&T Chemicals Inc., Woodbridge, NJ.

Evans, D.W. and R.B. Laughlin, Jr. 1984. Accumulation of bis(tributyltin) oxide by the mud crab, <u>Rhithropanopeus harrisii</u>. Chemosphere 13:213-219.

Filenko, O.F. and E.F. Isakova. 1980. The prediction of the effects of pollutants on aquatic organisms based on the data of acute toxicity

experiments. In: Proceedings of the third USA-USSR symposium on the effects of pollutants upon aquatic ecosystems. Swain, W.R. and V.R. Shannon (Eds.). EPA-600/9-80-034. National Technical Information Service, Springfield, VA. pp. 138-155.

Foster, R.B. 1981. Use of Asiatic clam larvae in aquatic hazard evaluations. In: Ecological assessments of effluent impacts on communities of indigenous aquatic organisms. Bates, J.M. and C.I. Weber (Eds.). ASTM STP 730. American Society for Testing and Materials, Philadelphia, PA. pp. 280-288.

Frick, L.P. and W.Q. DeJimenez. 1964. Molluscicidal qualities of three organo-tin compounds revealed by 6-hour and 24-hour exposures against representative stages and sizes of Australorbis glabratus. Bull. W. H. O. 31:429-431.

Good, M.L., V.H. Kulkarni, C.P. Monaghan and J.F. Hoffman. 1979. Antifouling marine coatings and their long term environmental impact. In: Proceedings of third coastal marsh and estuary management symposium: Environmental conditions in the Louisiana coastal zone. Day, J.W., Jr., D.D. Culley, Jr., A.J. Mumphrey, and R.E. Turner (Eds.). Division of Continuing Education, Louisiana State University, Baton Rouge, LA. pp. 19-30.

Good, M.L., D.S. Dundee and G. Swindler. 1980. Bioassays and environmental effects of organotin marine antifoulants. In: Controlled release of bioactive materials. Baker, R. (Ed.). Academic Press, New York, NY. pp. 387-398.

Gras, G. and J.A. Rioux. 1965. Structure-activity relationships. Oranotin insecticides (effects on larva of Culex pipiens pipiens L.). Arch. Inst. Pasteur Tunis 42:9-21.

Guard, H.E., W.M. Coleman, III and A.B. Cobet. 1982. Speciation of tributyltin compounds in seawater and estuarine sediments. In: Proceedings of the 185th National Meeting of the American Chemical Society, Division of Environmental Chemistry, Las Vegas, NV. 22(1):180-183.

Gucinski, H. 1986. The effect of sea surface microlayer enrichment on TBT transport. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1266-1274.

Hall, L.W., Jr. and A.E. Pinkney. 1985. Acute and sublethal effects of organotin compounds on aquatic biota: An interpretative literature evaluation. Crit. Rev. Toxicol. 14:159-209.

Hall, L.W., Jr., A.E. Pinkney, S. Zeger, E.T. Burton and M.J. Lenkevich. 1984. Behavioral responses to two estuarine fish species subjected to bis(tri-n-butyltin) oxide. Water Resour. Bull. 20:235-239.

Hall, L.W., Jr., M.J. Lenkevich, W.S. Hall, A.E. Pinkney and S.J. Bushong. 1986. Monitoring organotin concentrations in Maryland waters of Chesapeake Bay. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1275-1279.

Hall, L.W., Jr., S.J. Bushong, W.S. Hall and W.E. Johnson. 1987. Progress report: Acute and chronic effects of tributyltin on a Chesapeake Bay copepod. Johns Hopkins University, Shady Side, MD.

Henderson, R.S. 1986. Effects of organotin antifouling paint leachates on Pearl Harbor organisms: A site specific flowthrough bioassay. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1226-1233.

His, E. and R. Robert. 1980. Effect of tributyltin acetate on eggs and larvae of _Crassostrea gigas_. Int. Counc. Explor. Sea, Mariculture Committee F:27.

Hnath, J.G. 1970. Di-n-butyltin oxide as a vermifuge on _Eubothrium crassum_ (Block, 1779) in rainbow trout. Prog. Fish-Cult. 32:47-50.

Hodge, V.F., S.L. Seidel and E.D. Goldberg. 1979. Determination of tin(IV) and organotin compounds in natural waters, coastal sediments, and macro algae by atomic absorption spectrometry. Anal. Chem. 51:1256-1259.

Holwerda, D.A. and H.J. Herwig. 1986. Accumulation and metabolic effects of di-n-butyltin dichloride in the freshwater clam, _Anodonta anatina_. Bull. Environ. Contam. Toxicol. 36:756-762.

Hopf, H.S. and R.L. Muller. 1962. Laboratory breeding and testing of _Australorbis glabratus_ for molluscicidal screening. Bull. W. H. O. 27:783-389.

57

International Joint Commission. 1976. Water quality objectives subcommittee. Task force on scientific basis for water quality criteria. Great Lakes Water Quality Board, Research Advisory Board.

Jensen, K. 1977. Organotin compounds in the aquatic environment. A survey. Biokon Rep. 4:1-8.

Jonas, R.B., C.C. Gilmour, D.L. Stoner, M.W. Weir and J.H. Tuttle. 1984. Comparison of methods to measure acute metal and organometal toxicity to natural aquatic microbial communities. Appl. Environ. Microbiol. 47:1005-1011.

Kimbrough, R.D. 1976. Toxicity and health affects of selected organotin compounds: A review. Environ. Health Perspect. 14:51-56.

Kinnetic Laboratory. 1984. Status of knowledge concerning environmental concentrations and effects of tributyltin in aquatic systems. Final Report to Electric Power Research Institute. KLI-R-84-9. KLI, Santa Cruz, CA.

Kolosova, L.V., V.N. Nosov and I.Q. Dobrovolskii. 1980. Structure of hetero-organic compounds and their effect on Daphnia. Hydrobiol. J. (Engl. Transl. Gidrobiol. Zh.) 16(3):184-193.

Kumar Das, V.G., L.Y. Kuan, K.I. Sudderuddin, C.K. Chang, V. Thomas, C.K. Yap, M.K. Lo, G.C. Ong, W.K. Ng and Y. Hoi-sen. 1984. The toxic effects of triorganotin(IV) compounds on the culicine mosquito, Aedes aegypti (L.). Toxicology 32:57-66.

Kumpulainen, J. and P. Koivistoinen. 1977. Advances in tin compound analysis with special reference to organotin pesticide residues. Residue Rev. 66:1-18.

Laughlin, R.B., Jr. 1983. Physicochemical factors influencing toxicity of organotin compounds to crab zoeae, _Rhithropanopeus harrisii_. Abstract from Annual Meeting of the American Society of Zoologists, Philadelphia, PA. 23:1004

Laughlin, R.B., Jr. 1986. Bioaccumulation of tributyltin: The link between environment and organism. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1206-1209.

Laughlin, R.B., Jr. and W.J. French. 1980. Comparative study of the acute toxicity of a homologous series of trialkyltins to larval shore crabs, _Hemigrapsus nudus_, and lobster, _Homarus americanus_. Bull. Environ. Contam. Toxicol. 25:802-809.

Laughlin, R.B., Jr. and W. French. Manuscript. Concentration dependence of bis(tributyl)tin accumulation in the marine mussel, _Mytilus edulis_. Paper presented at the Ocean Dumping Symposium, April 20-25, 1986.

Laughlin, R. and O. Linden. 1982. Sublethal responses of the tadpole of the European frog, _Rana temporaria_, to two tributyltin compounds. Bull. Environ. Contam. Toxicol. 28:494-499.

Laughlin, R.B., Jr. and O. Linden. 1985. Fate and effects of organotin compounds. Ambio 14:88-94.

Laughlin, R.B., Jr., O. Linden and H.E. Guard. 1982. Acute toxicity of tributyltins and tributyltin leachates from marine antibiofouling paints. Bull. Liaison Comite Int. Perm. Recher. Reser. Mater. Milieu Marin 13:3-26.

Laughlin, R.B., Jr., W. French and H.E. Guard. 1983. Acute and sublethal toxicity of tributyltin oxide (TBTO) and its putative environmental product, tributyltin sulfide (TBTS) to zoel mud crabs, Rhithropanopeus harrisii. Water Air Soil Pollut. 20:69-79.

Laughlin, R.B., Jr., W. French, R.B. Johannesen, H.E. Guard and F.E. Brinckman. 1984a. Predicting toxicity using computed molecular topologies: The example of triorganotin compounds. Chemosphere 13:575-584.

Laughlin, R.B., Jr., K. Nordlund and O. Linden. 1984b. Long-term effects of tributyltin compounds on the baltic amphipod, Gammarus oceanicus. Mar. Environ. Res. 12:243-271.

Laughlin, R.B., Jr., R.B. Johannesen, W. French, H. Guard and F.E. Brinckman. 1985. Structure-activity relationships for organotin compounds. Environ. Toxicol. Chem. 4:343-351.

Laughlin, R.B., Jr., H.E. Guard and W.M. Coleman, III. 1986a. Tributyltin in seawater: Speciation and octanol-water partition coefficient. Environ. Sci. Technol. 20:201-204.

Laughlin, R.B., Jr., W. French and H.E. Guard. 1986b. Accumulation of bis(tributyltin) oxide by the marine mussel Mytilus edulis. Environ. Sci. Technol. 20:884-890.

Laughlin, R.B., Jr., P. Pendoley and R.G. Gustafson. Manuscript. Sublethal effects of tributyltin on the hard clam, Mercenaria mercenaria. Harbor Branch Foundation, FL.

Lee, R.F. 1985. Metabolism of tributyltin oxide by crabs, oysters and fish. Mar. Environ. Res. 17:145-148.

Lee, R.F. 1986. Metabolism of bis(tributyltin)oxide by estuarine animals. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1182-1188.

Linden, E., B. Bengtsson, O. Svanberg and G. Sundstrom. 1979. The acute toxicity of 78 chemicals and pesticide formulations against two brackish water organisms, the bleak (Alburnus alburnus) and the harpacticoid Nitocra spinipes. Chemosphere 8:843-851.

Maguire, R.J. 1984. Butyltin compounds and inorganic tin in sediments in Ontario. Environ. Sci. Technol. 18:291-294.

Maguire, R.J. 1986. Review of the occurrence, persistence and degradation of tributyltin in fresh water ecosystems in Canada. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1252-1255.

Maguire, R.J. and R.J. Tkacz. 1985. Degradation of the tri-n-butyltin species in water and sediment from Toronto harbor. J. Agric. Food Chem. 33:947-953.

Maguire, R.J., Y.K. Chau, G.A. Bengert, E.J. Hale, P.T. Wong and O. Kramar. 1982. Occurrence of organotin compounds in Ontario lakes and rivers. Environ. Sci. Technol. 16:698-702.

Maguire, R.J., J.H. Carey and E.J. Hale. 1983. Degradation of the tri-n-butyltin species in water. J. Agric. Food Chem. 31:1060-1065.

Maguire, R.J., P.T.S. Wong and J.S. Rhamey. 1984. Accumulation and metabolism of tri-n-butyltin cation by a green alga, Ankistrodesmus falcatus. Can. J. Fish. Aquat. Sci. 41:537-540.

Maguire, R.J., R.J. Tkacz and D.L. Santor. 1985. Butyltin species and inorganic tin in water sediment of the Detroit and St. Clair Rivers. J. Great Lakes Res. 11:320-327.

Mathias, C.C., J. Bellama, G. Olson and F. Brinkman. 1986. Comprehensive method for the determination of aquatic butyltin and butylmethyltin species at ultratrace levels using simultaneous hybridization/extraction with gas chromatographic-flame photometric detection. Environ. Sci. Technol. 20:609-615.

McCullough, F.S., P.H. Gayral, J. Duncan and J.D. Christie. 1980. Molluscicides in schistosomiasis control. Bull. W. H. O. 58:681-689.

Meador, J.P. 1986. An analysis of photobehavior of Daphnia magna exposed to tributyltin. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1213-1218.

Monaghan, C.P., E.J. O'Brien, Jr., H. Reust and M.L. Good. 1980. Current status of the chemical speciation of organotin toxicants in antifoulants. Dev. Ind. Microbiol. 21:211-215.

Mottley, J. 1978. Studies on the modes of action of n-alkylguanidines and triorganotins on photosynthetic energy conservation in the pea and the unicellular alga Chlamydomonas reinhardi Dangeard. Pestic. Biochem. Physiol. 9:340-350.

Newton, F., A. Thum, B. Davidson, A. Valkirs and P. Seligman. 1985. Effects on the growth and survival of eggs and embryos of the California grunion (Leuresthes tenuis) exposed to trace levels of tributyltin. NOSC-TR-1040 or AD-A162-445-1. National Technical Information Service, Springfield, VA.

Nishiuchi, Y. and K. Yoshida. 1972. Toxicities of pesticides to fresh water snails. Bull. Agric. Chem. Insp. Stn. (Tokyo) 12:86-92.

North Carolina Department of Natural Resources and Community Development. 1983. Investigation of the effects and uses of biocides and related compounds in North Carolina. Report No. 83-09. Division of Environmental Management, Water Quality Section, Raleigh, NC.

North Carolina Department of Natural Resources and Community Development. 1985. Triorganotin regulations in North Carolina. Division of Environmental Management, Water Quality Section, Planning Branch, Raleigh, NC.

Nosov, V.N. and L.V. Kolosova. 1979. Features of a toxicological curve as a function of the chemical structure of hetero-organic compounds. Biol. Nauki 22:97-101.

Pinkney, A.E., L.W. Hall, Jr., M.L. Lenkevich, D.T. Burton and S. Zeger. 1985. Comparison of avoidance responses of an estuarine fish, _Fundulus heteroclitus_, and crustacean, _Palaemonetes pugio_, to bis(tri-n-butyltin) oxide. Water Air Soil Pollut. 25:33-40.

Piver, W.T. 1973. Organotin compounds: Industrial applications and biological investigation. Environ. Health Perspect. 4:61-79.

Polster, M. and K. Halacha. 1972. Hygenic-toxicological problems of some antimicrobially-used organotin compounds. Ernaehrungsforschung 16:527-535.

Pope, D.H. 1981. Effect of biocides on algae and legionnaires disease bacteria. DE81-028768. National Technical Information Service, Springfield, VA.

Quick, T. and N.E. Cardarelli. 1977. Environmental impact of controlled release molluscicides and their degradation products: A preliminary report. In: Controlled release pesticides. Scher, H.B. (Ed.). ACS Symposium Series No. 53. American Chemical Society, Washington, DC. pp. 90-104.

Ritchie, L.S., L.A. Berrios-Duran, L.P. Frick and I. Fox. 1964. Molluscicidal time-concentration relationships of organo-tin compounds. Bull. W. H. O. 31:147-149.

Robert, R. and E. His. 1981. The effects of tributyltin acetate on the eggs and larvae of the two commercially important molluscs _Crassostrea gigas_ (Thurberg) and _Mytilus galloprovincialis_ (Link). Int. Counc. Explor. Sea, Mariculture Committee F:42.

Roberts, M.H., Jr. Manuscript. Acute toxicity of tributyltin chloride to embryos and larvae of two bivalve molluscs, _Crassostrea virginica_ and _Mercenaria mercenaria_. Virginia Institute of Marine Science, Gloucester Point, VA.

Salazar, M.H. and S.M. Salazar. 1985a. The effects of sediment on the survival of mysids exposed to organotins. Paper presented at the 11th U.S.-Japan experts meeting on management of sediments containing toxic substances, Nov. 4-6, 1985, Seattle, WA.

Salazar, M.H. and S.M. Salazar. 1985b. Ecological evaluation of organotin-contaminated sediment. NOSC-TR-1050 or AD-A160-748-0. National Technical Information Service, Springfield, VA.

Salazar, M.H. and S.M. Salazar. Manuscript. Acute effects of (bis)tributyltin oxide on marine organisms. Naval Oceans Systems Center, San Diego, CA.

Salazar, S.M. 1985. The effects of bis(tri-n-butyltin) oxide on three species of marine phytoplankton. NOSC-TR-1039 or AD-A162-115-0. National Technical Information Service, Springfield, VA.

Santos, A.T., M.J. Santos, B.L. Blas and E.A. Banez. 1977. Field trials using slow release rubber molluscicide formulations. MT-1E (Biomet SRM) and CBL-9B.

In: Controlled release pesticides. Scher, H.B. (Ed.). ACS Symposium Series No. 53. American Chemical Society, Washington, DC. pp. 114-123.

Seiffer, E.A. and H.F. Schoof. 1967. Tests of 15 experimental molluscicides against <u>Australorbis glabratus</u>. Public Health Rep. 82:833-839.

Seinen, W., T. Helder, H. Vernij, A. Penninks and P. Leeuwangh. 1981. Short term toxicity of tri-n-butyltin chloride in rainbow trout (<u>Salmo gairdneri</u> Richardson) yolk sac fry. Sci. Total Environ. 19:155-166.   .

Seligman, P.F., A.O. Valkirs and R.F. Lee. 1986. Degradation of tributyltin in San Diego Bay, CA waters. Draft Report. Naval Ocean Systems Center, San Diego, CA.

Sherman, L.R. 1983. A model for the controlled release of tri-n-butyltin fluoride from polymeric molluscicides and mosquito larvicides. J. Appl. Polymer Sci. 28:2823-2829.

Sherman, L.R. and H. Hoang. 1981. The bioassay and analysis of tributyltin fluoride. Anal. Proc. 18:196-198.

Sherman, L.R. and J.C. Jackson. 1981. Tri-n-butyltin fluoride as a controlled-release mosquite larvicide. In: Controlled release of pesticides and pharmaceuticals. Lewis, D.H. (Ed.). Plenum Press, New York, NY. pp. 287-294.

Shiff, C.J., C. Yiannakis and A.C. Evans. 1975. Further trials with TBTO and other slow release molluscicides in Rhodesia. In: Proceedings of 1975

international controlled release pesticide symposium. Harris, F.W. (Ed.). Wright State University, Dayton, OH. pp. 177-188.

Short, J.W. and F.P. Thrower. 1986a. Accumulation of butyltins in muscle tissue of chinook salmon reared in sea pens treated with tri-n-butyltin. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1177-1181.

Short, J.W. and F.P. Thrower. 1986b. Tri-n-butyltin caused mortality of chinook salmon, Onchorhynchus tshawytscha, on transfer to a TBT-treated marine net pen. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1202-1205.

Short, J.W. and F.P. Thrower. 1986c. Accumulation of butyltins in muscle tissue of chinook salmon reared in sea pens treated with tri-n-butyltins. Mar. Pollut. Bull. 17:542-545.

Slesinger, A.E. and I. Dressler. 1978. The environmental chemistry of three organotin chemicals. In: Report of the organotin workshop. Good, M. (Ed.). University of New Orleans, New Orleans, LA. pp. 115-162.

Smith, S.B. 1981. Male characteristics on female mud snails caused by antifouling bottom paints. J. Appl. Toxicol. 1:22-25.

Springborn Bionomics. 1984a. Acute and chronic toxicity of tributyltin fluoride to Pacific oyster (Crassostrea gigas). Report submitted to M&T Chemicals Inc., Rahway, NJ.

Springborn Bionomics. 1984b. Effects of tributyltin fluoride on survival,
growth, and development of sheepshead minnow (<u>Cyprinodon variegatus</u>). Report
B4-84-7 to M&T Chemicals Inc., Rahway, NJ.

Stebbing, A.R.D. 1985. Organotins and water quality, some lessons to be
learned. Mar. Pollut. Bull. 16:383-390.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A.
Brungs. 1985. Guidelines for deriving numerical national water quality
criteria for the protection of aquatic organisms and their uses. PB85-227049.
National Technical Information Service, Springfield, VA.

Stephenson, M.D., D.R. Smith, J. Goetzl, G. Ichikawa and M. Martin. 1986.
Growth abnormalities in mussels and oysters from areas with high levels of
tributyltin in San Diego Bay. In: Oceans '86 conference record, Vol. 4:
Organotin symposium. Marine Technology Society, Washington, DC. pp. 1246-1251.

Stroganov, N.S., V.G. Khobotev and L.V. Kolosova. 1972. Study of the
connection of the chemical composition of organometallic compounds with their
toxicity for hydrobionts. PB-208082. National Technical Information Service,
Springfield, VA.

Stroganov, N.S., O. Danil'chenko and E.H. Amochaeva. 1977. Changes in
developmental metabolism of the mollusc <u>Lymnaea stagnalis</u> under the effect of
tributyltin chloride in low concentrations. Biol. Nauki 20:75-78.

Stromgren, T. and T. Bongard. 1987. The effect of tributyltin oxide on growth
of <u>Mytilus edulis</u>. Mar. Pollut. Bull. 18:30-31.

Thain, J.E. 1983. The acute toxicity of bis(tributyltin) oxide to the adults and larvae of some marine organisms. Int. Counc. Explor. Sea, Mariculture Committee E:13.

Thain, J.E. 1986. Toxicity of TBT to bivalves: Effects on reproduction, growth and survival. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1306-1313.

Thain, J.E. and M.J. Waldock. 1985. The growth of bivalve spat exposed to organotin leachates from antifouling paints. Int. Counc. Explor. Sea, Mariculture Committee E:28.

Thayer, J.S. 1984. Organometallic compounds and living organisms. Academic Press, Orlando, FL.

Thompson, J.A.J., M.G. Sheffer, R.C. Pierce, Y.K. Chau, J.J. Cooney, W.R. Cullen and R.J. Maguire. 1985. Organotin compounds in the aquatic environment: Environmental quality. NRCC 22494. National Research Council Canada, Ottawa, Canada.

Tsuda, T., H. Nakanishi, S. Aoki and J. Takebayashi. 1986. Bioconcentration of butyltin compounds by round crucian carp. Toxicol. Environ. Chem. 12:137-143.

U.S. EPA. 1975. Preliminary investigation of effects on the environment of boron, indium, nickel, selenium, tin, vanadium and their compounds. Vol. V Tin. EPA-560/2-75-005. National Technical Information Service, Springfield, VA.

U.S. EPA. 1985a. Appendix B - Response to public comments on "Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses." Federal Regist. 50:30793-30796. July 29.

U.S. EPA. 1985b. Tributyltin support document. Office of Pesticides and Toxic Substances. Washington, DC.

U.S. Navy. 1984. Environmental assessment. Fleetwide use of organotin antifouling paint. U.S. Naval Sea Systems Command, Washington, DC.

Unger, M.A., W.G. MacIntyre, J. Greaves and R.J. Huggett. 1986. GC determination of butyltins in natural waters by flame photometric detection of hexyl derivatives with mass spectrometric confirmation. Chemosphere 15:461-470.

Upatham, E.S. 1975. Field studies on slow-release TBTO-pellets (Biomet SRM) against St. Lucian Biomphalaria glabrata. In: Proceedings of 1975 international controlled release pesticide symposium. Harris, F.W. (Ed.). Wright State University, Dayton, OH. pp. 189-195.

Upatham, E.S., M. Koura, M.A. Dagal, A.H. Awad and M.D. Ahmed. 1980a. Focal control of Schistosoma haematobium-transmitting snails, Bulinus (Ph.) abyssinicus, using controlled release tri-n-butyltin fluoride and copper sulphate. In: Controlled release of bioactive materials. Baker, R. (Ed.). Academic Press, New York, NY. pp. 449-459.

Upatham, E.S., M. Koura, M.D. Ahmed and A. H. Awad. 1980b. Laboratory trials of controlled release molluscicides on Bulinus (Ph.) abyssinicus, the

intermediate host of <u>Schistosoma</u> <u>haematobium</u> in Somalia. In: Controlled release of bioactive materials. Baker, H. (Ed.). Academic Press, New York, NY. pp. 461-469.

U'ren, S.C. 1983. Acute toxicity of bis(tributyltin) oxide to a marine copepod. Mar. Pollut. Bull. 14:303-306.

Valkirs, A., B. Davidson and P. Seligman. 1985a. Sublethal growth effects and mortality to marine bivalves and fish from long-term exposure to tributyltin. NOSC-TR-1042 or AD-A162-629-0. National Technical Information Service, Springfield, VA.

Valkirs, A.O., P.F. Seligman, G. Vafa, P.M. Stang and V. Homer. 1985b. Speciation of butyltins and methyltins in seawater and marine sediments by hydride derivatization and atomic absorption detection. NOSC-TR-1037 or AD-A161-872-7. National Technical Information Service, Springfield, VA.

Valkirs, A.O., P.F. Seligman, P.M. Stang, V. Homer, S.H. Lieberman, G. Vafa and C.A. Dooley. 1986. Measurement of butyltin compounds in San Diego Bay. Mar. Pollut. Bull. 17:319-324.

Valkirs, A.O., B.M. Davidson and P.F. Seligman. 1987. Sublethal growth effects and mortality to marine bivalves from long-term exposure to tributyltin. Chemosphere 16:201-220.

Vighi, M. and D. Calamari. 1985. QSARs for organotin compounds on <u>Daphnia</u> <u>magna</u>. Chemosphere 14:1925-1932.

von Rumker, R., E.W. Lawless, A.F. Meiners, K.A. Lawrence, G.L. Kelso and F. Horay. 1974. Production, distribution, use and environmental impact potential of selected pesticides. PB-238795 or EPA-540/1-74-001. National Technical Information Service, Springfield, VA. pp. 334-348.

Waldock, M.J. and D. Miller. 1983. The determination of total and tributyltin in seawater and oysters in areas of high pleasure craft activity. Int. Counc. Explor. Sea, Mariculture Committee E:12.

Waldock, M.J. and J.E. Thain. 1983. Shell-thickening in Crassostrea gigas: Organotin antifouling or sediment induced? Mar. Pollut. Bull. 14:411-415.

Waldock, M.J., J. Thain and D. Miller. 1983. The accumulation and depuration of bis(tributyltin) oxide in oysters. A comparison between the Pacific oyster (Crassostrea gigas) and the European flat oyster (Ostrea edulis). Int. Counc. Explor. Sea, Mariculture Committee E:52.

Walker, K.E. 1977. Organotin contact studies. In: Controlled release pesticides. Scher, H.B. (Ed.). ACS Symposium Series No. 53. American Chemical Society, Washington, DC. pp. 124-131.

Walsh, G.E. 1986. Organotin toxicity studies conducted with selected marine organisms at EPA's Environmental Research Laboratory, Gulf Breeze, Florida. In: Oceans '86 conference record, Vol. 4: Organotin symposium. Marine Technology Society, Washington, DC. pp. 1210-1212.

Walsh, G.E., L.L. McLaughlan, E.M. Lores, M.K. Louie and C.H. Deans. 1985.
Effects of organotins on growth and survival of two marine diatoms,
Skeletonema costatum and Thalassiosira pseudonana. Chemosphere 14:383-392.

Ward, G.S., G.C. Cramm, P.R. Parrish, H. Trachman and A. Slesinger. 1981.
Bioaccumulation and chronic toxicity of bis tributyltin oxide (TBTO): Tests
with a saltwater fish. In: Aquatic Toxicology and Hazard Assessment. Branson,
D.R. and K.L. Dickson (Eds.). ASTM STP 737. American Society for Testing
Materials, Philadelphia, PA. pp. 183-200.

Webbe, G. and R.F. Sturrock. 1964. Laboratory tests of some new molluscicides
in Tanganyika. Ann. Trop. Med. Parasitol. 58:234-239.

Weis, J.S., J. Gottleib and J. Kwiatkowski. 1987. Tributyltin retards
regeneration and produces deformities of limbs in the fiddler crab, Uca
pugilator. Arch. Environ. Contam. Toxicol. 16:321-326.

Weisfeld, L.B. 1970. Evaluation of an accelerated test method for organotin
and organolead antifouling coating: Guppy mortality. J. Paint Technol.
42:564-568.

Wong, P.T., Y.K. Chau, O. Kramar and G.A. Bengert. 1982. Structure-toxicity
relationship of tin compounds on algae. Can. J. Fish. Aquat. Sci. 39:483-488.