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AMBIENT WATER QUALITY CRITERIA FOR TRIBUTYLTIN - 1988

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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.

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Introduction

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 organotin most toxic 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 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 occurs 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 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. A comprehension 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 May 1988.

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. (Manuscript) 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 ≤ 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 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 crustaceans, 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 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 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.

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 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. 1985). The 66-day LC50 for 2.5 to 4.1 cm blue mussels was 0.97 μg/L (Valkirs et al. 1985,1987). Growth of hard clams from fertilization to metamorphosis was reduced by 0.025 μg/L (Laughlin et al Manuscript). 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 ≥ 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 ≥ 0.1 μg/L (Henderson 1986; Valkirs et al. 1985). 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 ≥ 0.2818 μg/L (Laughlin et al. 1984b). Developmental rates and growth of larval mud crabs, Rhithropanopeus harrisii, were reduced by a 15-day exposure to ≥ 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. (1985), 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; EG&G Bionomics 1981b; Filenko and Isakova 1980; Holwerda and Herwig 1986; Kolosova et al. 1980; Laughlin 1983, Lee 1985; 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.

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 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*.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of Tributyltin does not exceed 0 0264 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.149 μg/L more than once every three years on the average.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of tributyltin does not exceed 0.010 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.268 μg/L more than once every three years on the average.

Implementation

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983a) and the Foreword to this document, a water quality criterion for aquatic life has regulatory impact only after it has been adopted in a state water quality standard. Such a standard specifies a criterion for a pollutant that is consistent with a particular designated use. With the concurrence of the U.S EPA, states designate one or more uses for each body of water or segment thereof and adopt criteria that are consistent with the use(s) (U.S. EPA 1983b,1987). In each standard a state may adopt the national criterion, if one exists, or if adequately justified, a site-specific criterion.

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1983b), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1985c). The averaging periods of "one hour" and "four days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some pollutants, and "three years" is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985c). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site-specific and/or pollutant-specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in state water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1985c), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985c, 1987)

Table I Acute Toxicity of Tributyltin to Aquatic Animals

Species	Method[a]	Chemical[b]	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)[c]	Species Mean Acute Value (µg/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 1987
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 1985

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 1985
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

Table I. (continued)

Species	Method[a]	Chemical[b]	Salinity (g/kg)	LC50 or EC50 (µg/L)[c]	Species Mean Acute Value (µg/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%

Table I (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 the authors provided data to demonstrate the similar toxicity of a pure TBT compound and the TBT from the paint formulation

[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 the authors provided data to demonstrate the similar toxicity of a pure TBT compound and the TBT from the paint formulation

Table 2 (continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	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, <u>Nitocra spinipes</u>	1 911	-
7	1 745	American lobster, <u>Homarus americanus</u>		1 745
6	1 460	Chinook salmon, <u>Oncorhynchus tshawytscha</u>	1 460	-
5	1 365	Hard clam, <u>Mercenaria mercenaria</u>	1 365	-
4	1 204	Pacific oyster, <u>Crassostrea gigas</u>	1 557	-
		Eastern oyster, <u>Crassostrea virginica</u>	0 9316	-
3	<0 9732	Mysid, <u>Metamysidopsis elongata</u>	<0 9732[d]	-
2	0 6326	Copepod, <u>Acartia tonsa</u>	0 6326	-
1	0 61	Mysid, <u>Acanthomysis sculpta</u>	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 a quantitative value, not a ... ss than" value in the calculation of the Final Acute Value This was the lowest concentration used in th... ily test and it killed 63% of the exposed mysids

Table 3 (continued)

<u>Fresh water</u>

Final Acute Value = 0 2972 μg/L

Criterion Maximum Concentration = (0 2972 μg/L) / 2 = 0 1486 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

Criterion Maximum Concentration = (0 5313 μg/L) / 2 = 0 2656 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 dysosmos*	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

Table 4 (continued)

Species	Chemical[a]	Hardness (mg/L as $CaCO_3$)	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
SALTWATER SPECIES						
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

Table 5. Bioaccumulation of Tributyltin by Aquatic Organisms

Species	Chemical[a]	Salinity (g/kg)	Concentration in Water (µg/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, *Crassostrea gigas*	TBTO	28-31 5	1 216	21	Soft parts	1,874[e]	Waldock et al 1983
Pacific oyster, *Crassostrea gigas*	TBTO	28-31 5	0 1460	21	Soft parts	6,047[e]	Waldock et al 1983
Pacific oyster, *Crassostrea gigas*	d	28 5-34 2	0 24	45	Soft parts	7,292[e]	Thain and Waldock 1985, Thain 1986
Pacific oyster, *Crassostrea gigas*	TBTO	29-32	1 557	56	Soft parts	2,300	Waldock and Thain 1983
Pacific oyster, *Crassostrea 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

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

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

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

Table 6 (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (μg/L)[b]	Reference
			SALTWATER SPECIES			
Natural microbial populations	TBTC	2 and 17	1 hr	Significant decrease in metabolism of nutrient substrates	4 454	Jonas et al 1984
Natural microbial populations	TBTC	2 and 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

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

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 1985,1987
Blue mussel (2 5 to 4 1 cm), *Mytilus edulis*	c	-	66 days	Significant decrease in shell growth	0 31	Valkirs et al 1985
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

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 1985
Eastern oyster (2 7-5 3 cm), *Crassostrea virginica*	d	-	67 days	No effect on survival	1 89	Valkirs et al 1985
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

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
European flat oyster (spat), <u>Ostrea</u> <u>edulis</u>	c	28 5-34 2	45 days	Decreased growth	0 2392	Thain and Waldock 1985, Thain 1986
European flat oyster (spat), <u>Ostrea</u> <u>edulis</u>	c	28 5-34 2	45 days	70% mortality	2 6	Thain and Waldock 1985, Thain 1986
European flat oyster (adult), <u>Ostrea</u> <u>edulis</u>	c	28-34	75 days	Complete inhibition of larval production	0 24	Thain 1986
European flat oyster (adult), <u>Ostrea</u> <u>edulis</u>	c	28-34	75 days	Retardation of sex change from male to female	0 24	Thain 1986
European flat oyster (adult), <u>Ostrea</u> <u>edulis</u>	c	28-34	75 days	Prevented gonadal development	2 6	Thain 1986
Hard clam (post larva), <u>Mercenaria</u> <u>mercenaria</u>	TBTC (95%)	-	96 hr	Inhibited swimming behavior	0 0007330	Becerra-Huencho 1984
Hard clam (post larva), <u>Mercenaria</u> <u>mercenaria</u>	TBTC (95%)	-	96 hr	Reduced number of animals developing a foot	0 002922	Becerra-Huencho 1984
Hard clam (embryo, larva), <u>Mercenaria</u> <u>mercenaria</u>	TBTO	-	14 days	Reduced growth	0 025	Laughlin et al 1987

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	Loughlin et al 1987
Hard clam (post larva), *Mercenaria mercenaria*	TBTO	-	25 days	100% dead Percent survival better than controls	1 0 7 5	Loughlin 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 1987
Copepod, *Eurytemora affinis*	TBTC	14 6	13 days	Reduced survival of neonates	0 224	Hall et al 1987
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	Loughlin et al 1984b
Amphipod (larva, juvenile), *Gammarus oceanus*	TBTF	7	8 wk	100% mortality	2 816	Loughlin et al 1984b
Amphipod (larva, juvenile), *Gammarus oceanus*	TBTO	7	8 wk	Reduced survival and growth	0 2920	Loughlin et al 1984b
Amphipod (larva, juvenile) *Gammarus oceanus*	TBTF	7	8 wk	Reduced survival and increased growth	0 2816	Loughlin et al 1984b

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Amphipod (adult), <u>Orchestia traskiana</u>	TBTO	30	9 days	Approx 80% mortality	9 732	Laughlin et al 1982
Amphipod (adult), <u>Orchestia traskiana</u>	TBTF	30	9 days	Approx 90% mortality	9 732	Laughlin et al 1982
Grass shrimp, <u>Palaemonetes pugio</u>	TBTO (95%)	9 9-11 2	20 min	No avoidance	30	Pinkney et al 1985
Mud crab (larva), <u>Rhithropanopeus harrisii</u>	TBTO	15	15 days	Reduced developmental rate and growth	14 60	Laughlin et al 1983
Mud crab (larva), <u>Rhithropanopeus harrisii</u>	TBTS	15	15 days	Reduced developmental rate and growth	18 95	Laughlin et al 1983
Mud crab (larva), <u>Rhithropanopeus harrisii</u>	TBTO	15	15 days	63% mortality	>24 33	Laughlin et al 1983
Mud crab (larva), <u>Rhithropanopeus harrisii</u>	TBTS	15	15 days	74% mortality	28 43	Laughlin et al 1983
Mud crab, <u>Rhithropanopeus harrisii</u>	TBTO	15	6 days	BCF=24 for carapace	5 937	Evans and Laughlin 1984
Mud crab, <u>Rhithropanopeus harrisii</u>	TBTO	15	6 days	BCF=6 for hepatopancreas	5 937	Evans and Laughlin 1984
Mud crab, <u>Rhithropanopeus harrisii</u>	TBTO	15	6 days	BCF=0 6 for testes	5 937	Evans and Laughlin 1984

Table 6. (continued)

Species	Chemical[a]	Salinity (g/kg)	Duration	Effect	Concentration (µg/L)[b]	Reference
Mud crab, <u>Rhithropanopeus harrisii</u>	TBTO	15	6 days	BCF=41 for gill tissue	5 937	Evans and Loughlin 1984
Mud crab, <u>Rhithropanopeus harrisii</u>	TBTO	15	6 days	BCF=1 5 for chelae muscle	5 937	Evans and Loughlin 1984
Fiddler crab, <u>Uca pugilator</u>	TBTO	25	≤24 days	Retarded limb regeneration and molting	0 5	Weis et al 1987
Atlantic menhaden (juvenile), <u>Brevoortia tyrannus</u>	TBTO	9-11	-	Avoidance	5 437	Hall et al 1984
Chinook salmon (adult), <u>Oncorhynchus tshawytscha</u>	TBTO	28	96 hr	BCF=4300 for liver	1 49	Short and Thrower 1986a,c
Chinook salmon (adult), <u>Oncorhynchus tshawytscha</u>	TBTO	28	96 hr	BCF=1300 for brain	1 49	Short and Thrower 1986a,c
Chinook salmon (adult), <u>Oncorhynchus tshawytscha</u>	TBTO	28	96 hr	BCF=200 for muscle	1 49	Short and Thrower 1986a,c
Mummichog, <u>Fundulus heteroclitus</u>	TBTO (95%)	9 9-11 2	20 min	Avoidance	3 7	Pinkney et al 1985
California grunion (gamete through embryo), <u>Leuresthes tenuis</u>	c	-	10 days	Significantly enhanced growth and hatching success	0 14-1 72	Newton et al 1985
California grunion (gamete through embryo), <u>Leuresthes tenuis</u>	c	-	10 days	50% reduction in hatching success	74	Newton et al 1985

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

[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 the authors provided data to demonstrate the similar toxicity of a pure TBT compound and the TBT from the paint formulation

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