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2001 UPDATE OF AMBIENT WATER QUALITY CRITERIA FOR CADMIUM

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U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

NOTICES

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John G. Eaton
(freshwater author)
Environmental Research Laboratory
Duluth, Minnesota

John H. Gentile
(saltwater author)
Environmental Research Laboratory
Narragansett, Rhode Island

Charles E. Stephan
(document coordinator)
Environmental Research Laboratory
Duluth, Minnesota

David J. Hansen
(saltwater coordinator)
Environmental Research Laboratory
Narragansett, Rhode Island

Statistical Support: John W. Rogers
Clerical Support: Terry L. Highland

Document Update: 2001

Gregory J. Smith
(freshwater contributor)
Great Lakes Environmental Center
Columbus, Ohio

Cindy Roberts
(document coordinator)
U.S. EPA
Health and Ecological Effects Criteria Division
Washington, D.C.

Statistical Support: Dan Tholen, Great Lakes Environmental Center, Traverse City, Michigan

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INTRODUCTION[1]

This update document provides guidance to States and Tribes authorized to establish water quality standards under the Clean Water Act (CWA) to protect aquatic life from acute and chronic effects of cadmium. Under the CWA, States and Tribes are to establish water quality criteria to protect designated uses. While this document constitutes U.S. EPA's scientific recommendations regarding ambient concentrations of cadmium, this document does not substitute for the CWA or U.S. EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on U.S. EPA, States, Tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. State and Tribal decision-makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate. U.S. EPA may change this guidance in the future.

Cadmium is a relatively rare element that is a minor nutrient for plants at low concentrations (Lane and Morel 2000; Lee et al. 1995; Price and Morel 1990), but is toxic to aquatic life at concentrations only slightly higher. It occurs mainly as a component of minerals in the earth's crust at an average concentration of 0.18 ppm (Babich and Stotzky 1978). Cadmium levels in soils usually range from approximately 0.01 to 1.8 ppm (Lagerwerff and Specht 1970). In natural freshwaters, cadmium sometimes occurs at concentrations of less than 0.1 μg/L, but in environments impacted by man, concentrations can be several micrograms per liter or greater (Abbasi and Soni 1986; Allen 1994; Annune et al. 1994; Flick et al. 1971; Friberg et al. 1971; Henriksen and Wright 1978; Nilsson 1970; Spry and Wiener 1991). Cadmium can enter the environment from various anthropogenic sources, such as by-products from zinc refining, coal combustion, mine wastes, electroplating processes, iron and steel production, pigments, fertilizers and pesticides (Hutton 1983; Pickering and Gast 1972).

The impact of cadmium on aquatic organisms depends on a variety of possible chemical forms of cadmium (Callahan et al. 1979), which can have different toxicities and bioconcentration factors. In most well oxygenated freshwaters that are low in total organic carbon, free divalent cadmium will be the predominant form. Precipitation by carbonate or hydroxide and formation of soluble complexes by chloride, sulfate, carbonate, and hydroxide should usually be of little importance. In saltwaters with

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[1] 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), hereafter referred to as the Guidelines, is necessary in order to understand the following text, tables, and calculations.

salinities from about 10 to 35 g/kg, cadmium chloride complexes predominate. In both fresh and saltwaters, particulate matter and dissolved organic material may bind a substantial portion of the cadmium, and under these conditions cadmium may not be bioavailable due to this binding (Callahan et al. 1979; Kramer et al. 1997).

Because of the variety of forms of cadmium (Callahan et al. 1979) and lack of definitive information about their relative toxicities, no available analytical measurement is known to be ideal for expressing aquatic life criteria for cadmium. Previous aquatic life criteria for cadmium (U.S. EPA 1980) were expressed in terms of total recoverable cadmium (U.S. EPA 1983a), but this measurement is probably too rigorous in some situations. U.S. EPA (1985) has also expressed cadmium criteria as acid-soluble cadmium in the past, but now recommends use of dissolved metal concentrations (operationally defined as the metal in solution that passes through a 0.45 μm membrane filter) to set and measure compliance with water quality standards (Prothro 1993; U.S. EPA 1993, 1994a).

The criteria presented herein supersede previous aquatic life water quality criteria for cadmium (U.S. EPA 1999a) because these new criteria were derived based on the most recent science. Whenever appropriate, a national criterion may be replaced by a site-specific criterion (U.S. EPA 1994a), which may include not only site-specific criterion concentrations (U.S. EPA 1994b), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA 1991). All concentrations are expressed as cadmium, not as the chemical tested. The latest literature search for information for this document was conducted in June 1999; some newer information was also used.

Because the revisions being considered build from principles set forth in the 1985 Guidelines (Stephen et al. 1985), it is useful to have some understanding of how those Guidelines are ordinarily applied: (1) Acute toxicity test data must be available for species from a minimum of eight diverse taxonomic groups. The diversity of tested species is intended to assure protection of various components of an aquatic ecosystem. (2) The Final Acute Value (FAV) is derived by extrapolation or interpolation to a hypothetical genus more sensitive than 95 percent of all tested genera. The FAV, which represents an LC50 or EC50, is divided by two in order to obtain an acute criterion protective of nearly all individuals in such a genus. (3) Chronic toxicity test data (longer-term survival, growth, or reproduction) must be available for at least three taxa. Most often the chronic criterion is set by determining an appropriate acute-chronic ratio (the ratio of acutely toxic concentrations to the chronically toxic concentrations) and applying that ratio to the acute value of the hypothetical genus more sensitive than 95 percent of all tested genera. If sufficient data are available to meet the eight diverse taxonomic group minimum, then the chronic value is derived using the same procedure as used for the FAV derivation. (4) When necessary, the acute and/or chronic criterion may be lowered to protect recreationally or commercially important species. (5) When evaluating time-variable ambient concentrations generally, 1-hour average concentration are considered to be appropriate for comparison with the acute criterion, and 4-day averages with the chronic criterion. (6) The allowable frequency for exceeding a criterion is set at once every three years, on the average.

ACUTE TOXICITY TO FRESHWATER ANIMALS

Acceptable data on the acute effects of cadmium in freshwater are available for 39 species of invertebrates, 24 species of fish, one salamander species, and one frog species (Table 1a). These 65 species satisfy the eight different family requirements specified in the Guidelines. A tendency for increased tolerance to toxicity with increasing size or age has been reported (Table 1a) in the snail, *Physa gyrina* (Wier and Walter 1976), the coho salmon (Chapman 1975), and the common carp (Suresh et al. 1993a). No such effect was observed with increasing age (Table 1a) in the cladoceran, *Daphnia magna* (Stuhlbacher et al. 1993), the rainbow trout (Chapman 1975, 1978), or in the striped bass (Hughes 1973; Palawski et al. 1985). Data are unavailable for a sufficient number of species and life stages to allow general adjustment of test results or criteria on the basis of size or life stage. Where relationships were apparent between life-stage and sensitivity, only values for the most sensitive life-stage were considered.

Water Quality Parameters Affecting Toxicity

Although many factors might affect the results of tests of the toxicity of cadmium to aquatic organisms (Sprague 1985), water quality criteria can quantitatively take into account only factors for which enough data are available to show that the factor similarly affects the results of tests with a variety of species. Hardness is often thought of as having a major effect on the toxicity of cadmium, although the observed effect may be due to one or more of a number of usually interrelated ions, such as hydroxide, carbonate, calcium, and magnesium. Acute tests were conducted at three different levels of water hardness with *Daphnia magna* (Chapman et al. Manuscript), demonstrating that daphnids were at least five times more sensitive to cadmium in soft water than in hard water (Table 1a). Data in Table

1a also indicate that cadmium was more toxic to the tubificid worms *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, the mussel *Vilosa vibex*, *Daphnia pulex*, chinook salmon, goldfish, fathead minnow, guppy, striped bass, green sunfish and bluegill in soft than in hard water. Carroll et al. (1979) found that calcium, but not magnesium, reduced the acute toxicity of cadmium.

Other water quality characteristics could potentially influence the toxicity of cadmium to aquatic species. Giesy et al. (1977) found that dissolved organics substantially reduced the toxicity of cadmium to daphnids, but had little effect on its toxicity to fish. No consistent relationship between toxicity and organic particle size was observed. Development of the "biotic ligand model" (BLM - formerly the "gill model") in recent years has attempted to better account for the bioavailability of metals to aquatic life. The BLM, which quantifies the capacity of metals to bind to the gills of aquatic organisms, has been proposed as a reliable method for estimating the bioavailable portion of dissolved metals in the water column based on site-specific water quality parameters such as alkalinity, pH and dissolved organic carbon (McGeer et al. 2000; Meyer et al. 1999; Pagenkopf 1983; Paquin et al. 1999; U.S. EPA 1999b, 2000). Future development of the BLM for cadmium may help better quantify the bioavailable fraction of cadmium. Nonetheless, the model is in the preliminary development phase for cadmium and it will likely not be available for a number of years still.

Hardness Correction

Currently, the primary quantitative correlation used to modify metal toxicity estimates is water hardness (viz. the U.S. EPA 1995 water quality criteria for cadmium). Hardness (as calcium or magnesium ions) almost certainly has some direct effect on cadmium toxicity (e.g., by influencing membrane integrity). Calcium and magnesium ions compete with the metal for binding sites on the gill (Carroll et al. 1979; Evans 1987; Morel and Hering 1993; Pagenkopf 1983). Hardness also serves as a general surrogate for pH, alkalinity, and ionic strength, because waters of higher hardness usually have higher pH, alkalinity, and ionic strength. Other parameters such as pH, alkalinity, dissolved organic carbon, humic matter, ionic strength (anions and cations) and dissolved inorganic carbon also affect metal speciation and bioavailability, and thus metal toxicity. The pH is also important in determining the metal complexation capacity of dissolved organic matter.

Hardness is used here as a surrogate for the ions which affect the results of toxicity tests on cadmium. However, it should be emphasized that the hardness adjustment is not a precise measure, but an estimation. The variability associated with different life stages, clones and test conditions of the studies used to determine the hardness slope all contribute to the uncertainty of the hardness correction. In selected cases, only one life stage was used in the analysis (e.g., only adult fathead minnow data). Thus, in spite of all its limitations, hardness is currently the best surrogate available for metal toxicity adjustment.

To account for the apparent relationship of cadmium acute toxicity to hardness, an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the guidelines (Stephan et al. 1985) was performed using the Statistical Analysis System (SAS Inc., Cary, NC) software program to calculate the pooled slope for hardness using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. The pooled slope is a regression slope from a pooled data set, where every variable is adjusted relative to its mean. The species are adjusted separately, then pooled for a single conventional least squares regression analysis. The slope of the regression line is the best estimate of the all-species relationship between toxicity and hardness. With analysis of covariance, different species will be weighted relative to the number of data points they have. In this case, the *D. magna* and the fathead minnow each have 28 data points out of the total of 97, and the next most frequent species has just eight data points.

This analysis of covariance model was fit to the data in Table 1a for the 12 species for which definitive acute values (less than or greater than values were not used) are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest (other species in Table 1a either did not meet these criteria or did not show any hardness-toxicity trend due to differences in exposure methods, species age, etc.). For *D. magna*, only acute toxicity tests that were initiated with less than 24-hr old neonates were used to estimate the hardness slope. For the fathead minnow, only tests conducted with adults were used (not those conducted with the more sensitive fry life stage). A list of the species and acute toxicity-hardness values used to estimate the acute hardness slope is provided in Table 1d. The slopes for all 12 species ranged from 0.1086 to 2.031, and the pooled slope for these 12 species was 1.174 (see Table 1c). An F-test was used to test whether a model with separate species slopes for each species gives significantly better fit to the data than the model with parallel slopes. This test showed that the separate slopes model is not significantly better, and therefore the slopes are not significantly different than the overall pooled slope ($P=0.27$). The slopes and confidence intervals associated with the 12 species indicated that *D. magna* (all available data) had a very flat slope and a large confidence interval (and large standard error). If only the *D. magna* data from Chapman et al. (Manuscript) were used, the resultant *D. magna* slope was 1.182, with smaller confidence intervals than for the all *D. magna* slope. Likewise, when only the adult fathead minnow data were used (not the fry data), the resultant fathead minnow slope was 1.221 and smaller confidence intervals were present. If this reduced data set is used (all species but using only data from Chapman et al. (Manuscript) for *D. magna* and only adult fathead minnow data), the pooled slope for these species was 1.0166 (see Table 1c). The test for equality of the 12 slopes using the reduced data set (all species but only Chapman *D. magna* and adult fathead minnow data) produced P=0.69. Under analysis of covariance, it therefore is reasonable to assume that the slopes for these 12 species are the same, and that the overall slope is a reasonable estimate of the average relationship between hardness and toxicity. Either P value indicated that it was reasonable to assume that the slopes were the same, however, the second model was considered the better model and was therefore selected. The pooled slope of 1.0166 is close to the slope of 1.0 that is expected on the basis that cadmium, calcium, magnesium, and carbonate all have a charge of two (Meyer 1999). A plot of the acute effect level (EC50 or LC50) versus total hardness is provided in Figure 1.

The possible relationship of cadmium acute toxicity to water quality parameters other than hardness were also considered. Both hardness and/or alkalinity were investigated by subjecting any acute toxicity data in Table 1a having both hardness and alkalinity values available to a multiple stepwise regression analysis using the SAS (Cary, NC) software program. The analysis was run using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness and alkalinity as the covariates or independent variables. As with the analysis of covariance evaluation discussed above, the only data used in Table 1a (seven species) were those for which definitive acute values are available over a range of both hardness and alkalinity such that the highest hardness (and alkalinity) is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest. The results obtained indicate that either variable works well alone in the regression model (R^2 value for each was 0.688), but the other variable cannot increase the strength of the model once the first variable is included (when both were used the R^2 value only increased to 0.689). This lack of model improvement is due to the very strong correlation between hardness and alkalinity (effect of colinearity), thus these two independent variables should not be used together in the same regression model. Based on these results and the availability of data for water quality parameters other than hardness, the best approach at this time is to use only hardness (analysis of covariance discussed above) as a surrogate for the ions which affect the results of toxicity tests on cadmium.

Conversion Factors

Although past water quality criteria for cadmium (and other metals) have been established upon the loosely defined term of "acid soluble metals," U.S. EPA made the decision to allow the expression of metal criteria on the basis of dissolved metal (U.S. EPA 1994a), operationally defined as that metal that passes through a 0.45 micron filter. Because most of the data in existing databases are from tests that were either nominal concentrations, or provided only total cadmium measurements, some procedure was required to estimate their dissolved equivalents. The approach taken by U.S. EPA involves the use of conversion factors (CF), that when applied to the total metal concentration, gives a dissolved metal concentration. Thus, the CF corresponds to the percent of the total recoverable metal that is dissolved. These CFs were determined by conducting a number of "simulation tests" using solutions simulating those used in the toxicity tests that were most important in the derivation of aquatic life criteria for each metal (static, flow-through, fed, and unfed conditions that typified standard acute and chronic toxicity tests from which criteria are derived). The intent was to mimic the way criteria would have been derived if dissolved metal had been measured in each of the toxicity tests (Lussier et al. 1995; Stephan 1995; Univ. of Wisconsin-Superior 1995). For certain metals like cadmium, these CFs are hardness dependent.

The appropriate CFs were used only when determining the final cadmium criteria values, and are hardness dependent in freshwater. Acute freshwater total cadmium concentrations were converted to dissolved concentrations using the factor of 0.973 at a total hardness level of 50 mg/L as $CaCO_3$, 0.944 at a total hardness level of 100 mg/L as $CaCO_3$, and 0.915 at a total hardness level of 200 mg/L as $CaCO_3$. The equation for the acute freshwater conversion factor is CF = 1.136672 - [(ln hardness) (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephen 1995). Acute saltwater total cadmium values were converted to dissolved using the factor of 0.994.

Criteria Development

The pooled slope of 1.0166 was used to adjust the freshwater acute values in Table 1a to hardness = 50 mg/L, except where it was not possible because no hardness was reported. Species Mean Acute Values (SMAV) were calculated as geometric means of the adjusted acute values (only the underlined EC50/LC50 species values were used to calculate the respective SMAV). As stated in the

Guidelines (Stephen et al. 1985), flow-through measured study data are normally given preference over non-flow-through data for a particular species. In certain cases flow-through measured results were available, yet preference was given to the sensitive life stage for certain species in calculating SMAVs. In addition, all underlined Table 1a data for *D. magna* and fathead minnow fry were used to calculate the respective SMAVs (*D. magna* tests initiated with >24-hr old neonates were not used to calculate the SMAV). Only data from Chapman (1975) were used for coho salmon to avoid using test results from studies in which the life stage tested is known to be less sensitive, or in which the life stage tested is unreported and the higher LC50s may be due primarily to the use of less sensitive life stages. The data for Palawski et al. (1985) were used for striped bass because they were considered better data than those given in U.S. EPA (1985), although the data from Hughes (1973) support the newer data. Only brook trout data reported by Carroll et al. (1979), and not by Holcombe et al. (1983) were used in the calculation of the brook trout Final Acute Value because the reported bull trout data (Stratus Consulting 1999) in the same genus support the Carroll et al. (1979) results. Drummond and Benoit (Manuscript) reported that stress greatly affected the sensitivity of brook trout to cadmium.

The SMAV for freshwater invertebrates ranged from 13.41 μg/L total cadmium for the cladoceran, *D. magna* to 96,880 μg/L total cadmium for the midge, *Chironomus riparius*. Of the fish species tested, the brown trout, *Salmo trutta*, had the lowest SMAV of 1.613 μg/L total cadmium, and the tilapia, *Oreochromis mossambica*, recorded the highest fish SMAV of 10,663 μg/L total cadmium. As indicated by the data, both invertebrate and fish species display a wide range of sensitivities to cadmium.

Fish species represent eight of the nine most sensitive species to cadmium (Table 3a). Salmonids (*Salmo trutta*, *Salvelinus confluentus, Salvelinus fontinalis, Oncorhynchus kisutch, Oncorhynchus mykiss* and *Oncorhynchus tshawytscha*) are six of the seven most sensitive species listed in Table 1a, and thus are more acutely sensitive to cadmium than any other freshwater animal species thus far tested (Carroll et al. 1979; Chapman 1975, 1978, 1982; Cusimano et al. 1986; Davies et al. 1993; Finlayson and Verrue 1982; Phipps and Holcombe 1985; Spehar and Carlson 1984a,b; Stratus Consulting 1999). The cladoceran, *D. magna*, is the eighth most sensitive species to cadmium, and thus the most acutely sensitive invertebrate species tested thus far.

Genus Mean Acute Values (GMAV) at a hardness of 50 mg/L were then calculated (Table 3a) as geometric means of the available freshwater Species Mean Acute Values and ranked. Of the 55 genera for which acute values are available, the most sensitive genus, *Salmo*, is over 60,062 times more sensitive than the most resistant, *Chironomus*. The first through fourth most sensitive genera (a total n of 55) were used in the computation of the final acute value. The sensitivity of these four most sensitive genera are within a factor of 2.4, and all are fish. Of the ten most sensitive genera, six are fish, two are mussels, and two are cladocerans (Figure 2; Table 3a). Hardness-adjusted acute values are available for more than one species in nine genera, and the range of SMAVs within each genus is less than a factor of 4.0 for eight of the nine genera. The ninth genus, *Ptychocheilus*, has two SMAVs that differ by a factor of 98.5, possibly due to differences in the test conditions between species.

The freshwater Final Acute Value (FAV) for total cadmium at a hardness of 50 mg/L was calculated to be 2.763 μg/L total cadmium (Table 3d) from the Genus Mean Acute Values in Table 3a using the procedure described in the Guidelines. The Species Mean Acute Values for the rainbow trout, brook trout, bull trout and brown trout are lower than the FAV of 2.763 μg/L total cadmium, but the acute value for the brook trout and brown trout are from static tests, whereas flow-through measured tests have been conducted with the remaining two salmonid species. The freshwater Final Acute Value for total cadmium at a hardness of 50 mg/L was lowered to 2.108 μg/L to protect the commercially important rainbow trout (Table 3d). This value is above the SMAV of 1.613 μg/L for the brown trout and <1.791 μg/L for brook trout, but below all other SMAVs listed in Table 3a (Figure 2). The resultant freshwater Criterion Maximum Concentration (CMC) at a hardness of 50 mg/L for total cadmium (in μg/L) = $e^{(1.0166[\ln(\text{hardness})]-3.924)}$. If the CMC based on total cadmium values is converted to dissolved cadmium using the 0.973 factor at a hardness of 50 mg/L determined by U.S. EPA (Stephan 1995; Univ. of Wisconsin-Superior 1995), the freshwater CMC for dissolved cadmium (in μg/L) = 0.973 $[e^{(1.0166[\ln(\text{hardness})]-3.924)}]$. Thus, the 1.0 μg/L CMC for dissolved cadmium at a hardness of 50 mg/L is below all of the SMAVs presented in Table 3a (Figure 2). Conversion from total to dissolved was used because hardness relationships were established based upon total cadmium concentrations as this minimized the number of conversions required. In a few cases where only dissolved cadmium was reported in freshwater (Table 1a), conversion to total used the same appropriate factor.

ACUTE TOXICITY TO SALTWATER ANIMALS

Tests of the acute toxicity of cadmium to saltwater organisms have been conducted with 50 species of invertebrates and 11 species of fish (Table 1b), representing the required eight different taxonomic families. A pattern of increased tolerance to toxicity with increasing size or age has been reported (Table 1b) in the polychaete worm *Capitella capitata* (Reish and LeMay 1991; Reish et al. 1976), the blue mussel (Ahsanullah 1976; Martin et al. 1981; Nelson et al. 1988), the copepod *Eurytemora affinis* (Gentile 1982; Sullivan et al. 1983), the amphipods *Marinogammarus obtusatus* (Wright and Frain 1981) and *Leptocheirus plumulosus* (McGee et al. 1998), the pink shrimp *Penaeus duorarum* (Nimmo et al. 1977b; Cripe 1994), the rivulus (Park et al. 1994; Lin and Dunson 1993), the Atlantic silverside (Cardin 1982) and the striped mullet (Hilmy et al. 1985). No such effect was observed with increasing age (Table 1b) in the polychaete worm *Neanthes arenaceodentata* (Reish and LeMay 1991; Reish et al. 1976), the mysid *Americamysis bahia*, formerly *Mysidopsis bahia* (De Lisle and Roberts 1988), the grass shrimp *Palaemonetes pugio* (Khan et al. 1988; Burton and Fisher 1990), and the mummichog *Fundulus heteroclitus* (Voyer 1975). Data are unavailable for a sufficient number of species and life stages to allow general adjustment of test results or criteria on the basis of size or life stage. Where relationships were apparent between life-stage and sensitivity, only values for the most sensitive life-stage were considered.

Water Quality Parameters Affecting Toxicity

Frank and Robertson (1979) reported that the acute toxicity to juvenile blue crabs was related to salinity. The 96-hr LC50s were 320, 4,700, and 11,600 μg/L at salinities of 1, 15, and 35 g/kg, respectively (Table 1b). Studies with *A. bahia* by Gentile et al. (1982) and Nimmo et al. (1977a) also support a relationship between salinity and the acute toxicity of cadmium. O'Hara (1973a) investigated the effect of temperature and salinity on the toxicity of cadmium to the fiddler crab. The LC50s at 20°C were 32,300, 46,600, and 37,000 μg/L at salinities of 10, 20, and 30 g/kg, respectively. Increasing the temperature from 20 to 30°C lowered the LC50 at all salinities tested. Toudal and Riisgard (1987) reported that increasing the temperature from 13 to 21 °C at a salinity of 20 g/kg also lowered the LC50 value of cadmium to the copepod, *Acartia tonsa*.

Saltwater fish species were generally more resistant to cadmium than freshwater fish species with SMAVs ranging from 75.0 μg/L for the striped bass (at a salinity of 1 g/kg) to 50,000 μg/L for the sheepshead minnow (Table 3b). In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, Voyer (1975) found that 96-hr LC50s at a salinity of 32 g/kg were about one-half what they were at 10 and 20 g/kg. Sensitivity of the mummichog to acute cadmium poisoning was not influenced by reduction in dissolved oxygen concentration to 4 mg/L. This increase in toxicity with increasing salinity conflicts with other data reported in Tables 1b and 6b. Since there was no consistent salinity-toxicity trend observed for the data, a salinity correction factor was not attempted.

Criteria Development

Of the 54 saltwater genera for which acute values are available, the most sensitive, *Americamysis*, is 3,270 times more sensitive than the most resistant, *Monopylephorus* (Table 3b). The SMAVs for saltwater invertebrate species range from 41.29 μg/L for a mysid to 135,000 μg/L for an oligochaete worm (Tables 1b and 3b). The acute values for saltwater polychaetes range from 200 μg/L for *C. capitata* to 14,100 μg/L for *N. arenaceodentata* (Reish and LeMay 1991). Saltwater molluscs have Species Mean Acute Values from 227.9 μg/L for the Pacific oyster to 19,170 μg/L for the mud snail. Acute values are available for more than one species in each of seven genera, and the range of Species Mean Acute Values within each genus is no more than a factor of 3.6 for six of the seven genera. The seventh genus, *Crassostrea*, has two SMAVs that differ by a factor of 16.7, possibly due to different exposure conditions between species. Only the data from Reish et al. (1976) were used for *C. capitat*a, only data from Martin et al. (1981) and Nelson et al. (1988) were used for *M. edulis*, only data from Sullivan et al. (1983) were used for *E. affinis,* only data from Cripe (1994) were used for *P. duorarum*, and only data from Park et al. (1994) were used for *Rivulus marmoratus* to avoid using test results from studies in which the life stage tested is known to be less sensitive or in which the life stage tested is unreported and the higher LC50s may be due primarily to the use of less sensitive life stages. The sensitivities of the four most sensitive genera differed by a factor of 2.7, which includes two mysids, the striped bass and the American lobster (Table 3b).

The saltwater Final Acute Value for total cadmium calculated from the Genus Mean Acute Values in Table 3b is 80.55 μg/L. This Final Acute Value is below the SMAV for the mysid, *Mysidopsis bigelowi* (110 μg/L), but is aproximately three percent above the American lobster (78 μg/L), approximately seven percent higher than the striped bass (75.0 μg/L), and approximately 95 percent above the SMAV for the mysid, *A. bahia* (41.29 μg/L, geometric mean of two flow-through measured tests). The resultant saltwater Criterion Maximum Concentration (CMC) for total cadmium is 40 μg/L (FAV/2 or 80.55 μg/L/2). If the total cadmium CMC is converted to dissolved cadmium using the 0.994 factor determined experimentally by U.S. EPA, the saltwater CMC for dissolved cadmium is 40 μg/L (Table 3d). The resultant 40 μg/L CMC for dissolved cadmium is below all of the saltwater SMAVs presented in Table 3a (Figure 3).

CHRONIC TOXICITY TO FRESHWATER ANIMALS

Acceptable chronic toxicity tests have been conducted on cadmium in freshwater with 21 species, including seven invertebrates and 14 fishes in 16 genera (Table 2a). Several related values are in Table 6a. Among the unused values in Table 6a, a 21-day *Daphnia magna* test in which the test concentrations were not measured, Biesinger and Christensen (1972) found a 16 percent reduction in reproduction at 0.17 μg/L. Bertram and Hart (1979) and Ingersoll and Winner (1982) found chronic toxicity to *Daphnia pulex* at less than 1 and 10 μg/L, respectively. A 32-day flow-through measured juvenile bluegill study conducted by Cope et al. (1994) determined a growth NOEC value of >32.3 μg/L (Table 6a), which supports the 49.8 μg/L chronic value (Table 2a) reported by Eaton (1974). The 200-hr LC10 of 0.7 μg/L obtained with rainbow trout (Table 6a) by Chapman (1978) probably would be close to the result of an early life-stage test because of the extent to which various life stages were investigated. Effects on other salmonids and many invertebrates have been observed at 5 μg/L (adjusted for hardness when available) or less (Table 6a). These invertebrate species include protozoans (Fernandez-Leborans and Noville-Villajos 1993; Niederlehner et al. 1985), *C. dubia* (Winner 1988; Zuiderveen and Birge 1997), *D. magna* (Enserink et al. 1993; Winner and Whitford 1987), zooplankton (Lawrence and Holoka 1987), amphipods (Borgmann et al. 1991; Phipps et al. 1995), midges (Anderson et al. 1980), and mayflies (Spehar et al. 1978).

An acceptable *C. dubia* seven-day static-renewal toxicity test was conducted by Jop et al. (1995) using reconstituted soft laboratory water. The <24-hr old neonates were exposed to 1, 5, 10, 19 and 41 μg/L measured cadmium concentrations in addition to a laboratory water control at 25°C. The NOEC and LOEC were 10 and 19 μg/L cadmium, respectively, with a resultant chronic value of 13.78 μg/L cadmium (Table 2a).

The effects of water hardness on the toxicity of cadmium to *D. magna* was evaluated by Chapman et al. (Manuscript) under static-renewal conditions at a temperature of 20 $\pm$ 2°C. As part of the experimental design, the total hardness level was adjusted to either 53, 103 or 209 mg/L (as $CaCO_3$) in three distinct tests. Daphnids were individually exposed to six measured cadmium concentrations (exposures ranged from 0.15 to 22.1 μg/L cadmium among the three tests) and a control (0.08 μg/L cadmium) for 21 days. Based on an analysis of variance hypothesis testing procedure, they reported reproductive (mean number of young per adult) chronic values of 0.1523, 0.2117 and 0.4371 μg/L cadmium at hardness levels of 53, 103 and 209 mg/L, respectively (Table 2a). These same data were also subjected to a regression analysis procedure, whereby the 20 percent reproductive (mean number of young per adult) inhibition concentration (IC20) was estimated for each hardness level. The resultant IC20 values were 0.07, 0.23 and 0.33 μg/L cadmium for the 53, 103 and 209 mg/L hardness levels, respectively. Overall, the results obtained by the two different procedures are similar.

The effect of cadmium on the reproduction strategy of *D. magna* was investigated by Bodar et al. (1988b). After a 25-day exposure of the 12 ± 12-hr old neonates to 0 (control), 0.5, 1.0, 5.0, 10.0, 20.0 and 50 μg/L cadmium at 20 ± 1°C, the authors compared the survival, number of neonates per female, first day of reproduction and neonate size of the cadmium exposures to the controls. The 25-day reproductive NOEC was 5.0 μg/L cadmium, and the reproductive LOEC was 10.0 μg/L cadmium. The resultant chronic value was 7.07 μg/L cadmium (Table 2a).

Borgman et al. (1989) also investigated the effect of cadmium on *D. magna* reproduction. The 21-day static-renewal test was conducted at 20°C using measured exposure concentrations of 0.22 (control), 1.86, 4.10, 7.78 and 22.9 μg/L cadmium. Reproduction was significantly reduced at the lowest measured exposure concentration of 1.86 μg/L cadmium. Thus, the reproductive NOEC and LOEC were <1.86 and 1.86 μg/L cadmium, respectively, with a chronic value of <1.86 μg/L cadmium (Table 2a).

Brown et al. (1994) exposed 270-day old rainbow trout to cadmium under flow-through conditions for 65 weeks using borehole water with a total hardness of 250 mg/L (as $CaCO_3$). Mean cadmium concentrations during the exposure of adult fish were 0.47 (control), 1.77, 3.39 and 5.48 μg/L. After 65 weeks of exposure, the three most mature males and females were selected from each treatment, anesthetized and striped of their gametes when possible, with the milt and ova combined in a bucket. The fertilized eggs from each treatment group were then divided into four approximately equal-sized subsamples and exposed for seven weeks in 30-liter aquaria under flow-through conditions to nominal concentrations of 0 (control), 2.0, 5.0 and 8.0 μg/L cadmium. Second generation fry development was significantly affected when the parents were exposed to 1.77 μg/L cadmium, but not when exposed to 0.47 μg/L cadmium (control). However, second generation embryo survival for all groups was less than 60 percent, which may have influenced the fry development effect levels. A more representative endpoint was the ability of the first generation adults to reach sexual maturity, with NOEC and LOEC values of 3.39 and 5.48 μg/L cadmium, respectively. The resultant chronic value was 4.310 μg/L cadmium (Table 2a).

Brown et al. (1994) also exposed two-year old brown trout to cadmium under flow-through conditions for 95 weeks using the same borehole water. Mean cadmium concentrations during the exposure of adult fish were 0.27 (control), 5.13, 9.34 and 29.1 μg/L. After 60 weeks of exposure, the three most mature males and females were selected from each treatment, anesthetized and striped of their gametes, with the milt and ova combined in a bucket. The fertilized eggs from each treatment group were then divided into four approximately equal-sized subsamples and exposed for 50 days in 30-liter aquaria under flow-through conditions to cadmium concentrations similar to those in which the parents were exposed. After the 90 week exposure, the survival NOEC and LOEC were 9.34 and 29.1 μg/L cadmium, respectively, with a resultant chronic value of 16.49 μg/L cadmium (Table 2a).

A 32-day fathead minnow early life stage toxicity test was conducted by Spehar and Fiandt (1986) under flow-through conditions using sand filtered Lake Superior dilution water (Table 2a). They reported a chronic value of 10.0 μg/L cadmium, which when coupled with their 96-hour LC50 of 13.2 μg/L cadmium, gives an acute-chronic ratio of 1.320.

Ingersoll and Kemble (unpublished) investigated the chronic toxicity of cadmium to the amphipod *Hyalella azteca*. The organisms were exposed under flow-through measured conditions (control, low, middle and high exposures) at a mean temperature of 23°C and a total hardness of 280 mg/L (as $CaCO_3$). A 3-m nylon mesh substrate was provided during the test. The seven- to eight-day old amphipods were exposed to water only mean total cadmium concentrations of 0.10 (control), 0.12, 0.32, 0.51, 1.9 and 3.2 μg/L for 42 days. The most sensitive endpoint was survival, with an NOEC and LOEC of 0.51 and 1.9 μg/L cadmium, respectively, after both 28 and 42 days of exposure. The resultant chronic value was 0.9844 μg/L total cadmium (Table 2a), which was similar to the estimated 42-day survival IC25 value of 1.9 μg/L.

Ingersoll and Kemble (unpublished) also exposed the midge *Chironomus tentans* to cadmium under the same conditions listed above for the amphipod, except that a thin 5 mm layer of sand was provided as a substrate. The <24-hr old larvae were exposed to water only mean measured total cadmium concentrations of 0.15 (control), 0.50, 1.5, 3.1, 5.8 and 17.4 μg/L for 20 days. The mean weight, biomass, percent emergence and percent hatch endpoints all had 20-day NOEC and LOEC values of 5.8 and 17.4 μg/L cadmium, respectively (Table 2a). The resultant chronic value was 10.05 μg/L total cadmium. The data were also subjected to regression analysis with resultant IC25 values of 10.3, 10.7, 8.3 and 4.0 μg/L for weight, biomass, percent emergence and percent hatch, respectively.

All four IC25 values were similar to the 10.05 μg/L chronic value determined for each endpoint.

Hardness Correction

Chronic values are available over a wide range of hardness for three species (Tables 2a and 2d). To account for the apparent relationship of cadmium chronic toxicity to hardness, an analysis of covariance (same as the analysis performed on the acute data) was performed to calculate the pooled slope for hardness using the natural logarithm of the chronic value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. This analysis of covariance model was fit to the data in Table 2a for the three species for which definitive chronic values are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest (other species in Table 2a did not meet these criteria). The slopes for the three species ranged from 0.5212 to 1.579, and the pooled slope for these three species was 0.9685 with P=0.90 (Table 2c). As with the acute slope determination, the all *D. magna* data set was too divergent, and only the Chapman et al. (Manuscript) *D. magna* data were used with the two other species (brown trout and fathead minnow) to estimate the overall slope. If this reduced data set is used (all species but using only data from Chapman et al. (Manuscript) for *D. magna*), the pooled slope for these species was 0.7409 with P=0.35 (see Table 2c). A plot of the chronic effect level versus total hardness is provided in Figure 4.

Criteria Development

The slope of 0.7409 was used to adjust each chronic value to a hardness of 50 mg/L. Generally, replicate adjusted chronic values for a species agreed well, as did values for species within a genus. The two values for Atlantic salmon are very different, but one agrees well with the value for the other tested species in the same genus. Twenty-one Species Mean Chronic Values (SMCV) were then calculated from the underlined values in Table 2a. When both early life stage (ELS) and life cycle (LC) data were available for a species, the SMCV was calculated using only the LC data per the Guideline recommendations. From these 21 SMCVs, sixteen Genus Mean Chronic Values were calculated and ranked (Table 3c).

A freshwater Final Chronic Value was calculated from the sixteen Genus Mean Chronic Values using the procedure used to calculate a Final Acute Value. This approach was appropriate since a number of chronic tests have been conducted with a large variety of species and these species met the eight different taxonomic family Guideline requirement. Thus, the freshwater Final Chronic Value for total cadmium at a hardness of 50 mg/L is (in μg/L) = $e^{(0.7409[\ln(\text{hardness})]-4.719)}$, or equal to 0.16 μg/L. For dissolved cadmium, the Final Chronic value at a hardness of 50 mg/L is (in μg/L) = 0.938 $[e^{(0.7409[\ln(\text{hardness})]-4.719)}]$, or equal to 0.15 μg/L. The equation for the chronic freshwater conversion factor is CF = 1.101672 - [(ln hardness) (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephen 1995). At a hardness of 50 mg/L, all Genus Mean Chronic Values are above the dissolved Final Chronic Value (Figure 5).

Another option for calculating the Final Chronic Value is to use the Final Acute-Chronic Ratio in conjunction with the Final Acute Value. However, the acute-chronic ratios ranged from 0.9021 for the chinook salmon to 433.8 for the flagfish (greater than a factor of ten), with other values scattered throughout this range (Tables 2e and 3c). These ratios do not seem to follow any of the patterns (Table 3c) recommended in the Guidelines, and so it does not seem reasonable to use a freshwater Final Acute-Chronic Ratio to calculate a Final Chronic Value.

CHRONIC TOXICITY TO SALTWATER ANIMALS

Three chronic toxicity tests have been conducted with the saltwater invertebrate, *Americamysis bahia*, formerly classified as *Mysidopsis bahia* (Table 2b). Nimmo et al. (1977a) conducted a 23-day life-cycle test at 20 to 28°C and salinity of 15 to 23 g/kg. Survival was 10 percent at 10.6 μg/L, 84 percent at the next lower test concentration of 6.4 μg/L, and 95 percent in the controls. No unacceptable effects were observed at 6.4 μg/L or any lower concentration. The chronic toxicity limits, therefore, are 6.4 and 10.6 μg/L, with a chronic value of 8.237 μg/L. The 96-hr LC50 was 15.5 μg/L, resulting in an acute-chronic ratio of 1.882.

Another life-cycle test was conducted on cadmium with *A. bahia* under different environmental conditions, including a constant temperature of 21°C and salinity of 30 g/kg (Gentile et al. 1982; Lussier et al. 1985). All organisms died in 28 days at 23 μg/L. At 10 μg/L a series of morphological abberations occurred at the onset of sexual maturity. External genitalia in males were abberant, females failed to develop brood pouches, and both sexes developed a carapace malformation that prohibited molting after the release of the initial brood. Although initial reproduction at this concentration was successful, successive broods could not be born because molting resulted in death.

No malformations or effects on initial or successive reproductive processes were noted in the controls or at 5.1 µg/L. Thus, the chronic limits for this study are 5.1 and 10 µg/L for a chronic value of 7.141 µg/L (Table 2b). The LC50 at 21°C and salinity of 30 g/kg was 110 µg/L which results in an acute-chronic ratio of 15.40 from this study.

These two studies showed excellent agreement between the chronic values but considerable divergence between the acute values and acute-chronic ratios. Several studies have demonstrated an increase in acute toxicity of cadmium with decreasing salinity and increasing temperature (Table 6b). The observed differences in acute toxicity to the mysids might be explained on this basis. Nimmo et al. (1977a) conducted their acute test at 20 to 28°C and salinity of 15 to 23 g/kg, whereas the other test was performed at 21°C and salinity of 30 g/kg.

A third *A. bahia* chronic study was conducted by Carr et al. (1985) at a salinity of 30 g/kg, but the temperature varied from 14 to 26°C over the 33 day study (Table 2b). At test termination, >50 percent of the organisms had died in cadmium exposures ≥8 µg/L. After 18 days of exposure, growth in the 4 µg/L, the lowest concentration treatment group was significantly reduced when compared to the controls. The resultant chronic limits for this study are <4 and 4 µg/L cadmium. Acute data were not presented by the authors. The lower chronic value observed for this study as compared to the two studies described above may have been due to unexpected temperature fluctuations over the study period (due to mechanical problems).

Gentile et al. (1982) also conducted a life-cycle test with another mysid, *Mysidopsis bigelowi*, and the results were very similar to those for *A. bahia*. Thus, the chronic value was 7.141 µg/L and the acute-chronic ratio was 15.40.

Because they covered such a wide range, it would be inappropriate to use any of the available freshwater acute-chronic ratios in the calculation of the saltwater Final Chronic Value. The two saltwater species for which acute-chronic ratios are available (Table 3b) have Species Mean Acute Values in the same range as the saltwater Final Acute Value, and so it seems reasonable to use the geometric mean of these two ratios. When the saltwater Final Acute Value of 80.55 µg/L is divided by the mean acute-chronic ratio of 9.106, a saltwater Final Chronic Value of 8.9 µg/L is obtained. The dissolved cadmium FCV is computed using the CF (0.994 x 8.846 µg/L), and is equal to 8.8 µg/L.

TOXICITY TO AQUATIC PLANTS

Thirty-three acceptable tests are available with freshwater plant species exposed to cadmium which lasted from 4 to 28 days (Table 4a). Growth reduction was the major toxic effect observed with freshwater aquatic plants, and several values are in the range of concentrations causing chronic effects on animals. The influence that plant growth media might have had on the toxicity tests is unknown, but is probably minor at least in the case of Conway (1978) who used a medium patterned after natural Lake Michigan water. The freshwater plant and animal data presented in this document were compared and the lowest toxicity values for fish and invertebrate species are lower than the lowest values for plants. A plot of the freshwater plant values is provided in Figure 6a. Thus, water quality criteria which protect freshwater animals should also protect freshwater plants. A final plant value was not calculated.

Toxicity values are available for five species of saltwater diatoms and two species of macroalgae (Table 4b). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 60 μg/L for *Ditylum brightwelli* to 22,390 μg/L for *Phaeodactylum tricornutum*, the most resistant to cadmium. The brown macroalga (kelp) exhibited mid-range sensitivity to cadmium, with an EC50 of 860 μg/L. The most sensitive saltwater plant tested was the red alga, *Champia parvula*, with significant reductions in the growth of both the tetrasporophyte plant and female plant occurring at 22.8 μg/L. The saltwater plant and animal data were also compared, and the most sensitive plant species (*C. parvula*) is more resistant than the chronically most sensitive animal species tested. A plot of the saltwater plant values is provided in Figure 7. Therefore, water quality criteria for cadmium that protect saltwater animals should also protect saltwater plants. A final plant value was not calculated.

BIOACCUMULATION

Bioconcentration factors (BCFs) for cadmium in freshwater (Table 5a) range from 3 for brook trout muscle (Benoit et al. 1976) to 6,910 for the soft tissue of the snail *Viviparus georgianus* (Tessier et al. 1994b). Usually, fish accumulate only small amounts of cadmium in muscle as compared to most other tissues and organs (Benoit et al. 1976; Jarvinen and Ankley 1999; Sangalang and Freeman 1979). However, specific studies summarized by Jarvinen and Ankley (1999) showed that the skin, spleen, gill, fin, otolith and bone also have low bioconcentration factors. Sangalang and Freeman (1979) found that cadmium residues in fish reach steady-state only after exposure periods greatly exceeding 28 days. *D. magna*, and presumably other invertebrates of about this size or smaller, often reach steady-state within a few days (Poldoski 1979). Cadmium accumulated by fish from water is eliminated slowly (Benoit et al. 1976: Kumada et al. 1980), but Kumada et al. (1980) found that cadmium accumulated from food is eliminated much more rapidly. If all variables, except temperature, were kept the same, Tessier et al. (1994a) found that increased exposure temperatures generally increased the soft tissue bioconcentration factor observed for the snail, *V. georgianus*, but not for the mussel, *Elliptio complanata*. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by *D. magna*, but Winner (1984) did not find any effect. Ramamoorthy and Blumhagen (1984) reported that fulvic and humic acids increased uptake of cadmium by rainbow trout.

The only BCF reported for a saltwater fish is a value of 48 from a 21-day exposure of the mummichog (Table 6b). However, among ten species of invertebrates, the BCFs range from 22 to 3,160 for whole body and from 5 to 2,040 for muscle (Table 5b). The highest BCF was reported for the polychaete, *Ophryotrocha diadema* (Klockner 1979). Although a BCF of 3,160 was attained after sixty-four days exposure using the renewal technique, tissue residues had not reached steady-state.

BCFs for four species of saltwater bivalve molluscs range from 113 for the blue mussel (George and Coombs 1977) to 2,150 for the eastern oyster (Zaroogian and Cheer 1976). In addition, the range of reported BCFs is rather large for some individual species. BCFs for the oyster include 149 and 677 (Table 6b), as well as 1,220, 1,830 and 2,150 (Table 5b). Similarly, two studies with the bay scallop resulted in BCFs of 168 (Eisler et al. 1972) and 2,040 (Pesch and Stewart 1980) and three studies with the blue mussel reported BCFs of 113, 306, and 710 (Tables 5b and 6b). George and Coombs (1977) studied the importance of metal speciation on cadmium accumulation in the soft tissues of *Mytilus edulis*. Cadmium complexed as Cd-EDTA, Cd-alginate, Cd-humate, and Cd-pectate (Table 6b) was bioconcentrated at twice the rate of inorganic cadmium (Table 5b). Because bivalve molluscs usually do not reach steady-state, comparisons between species may be difficult and the length of exposure may be the major determinant in the size of the BCF.

BCFs for five species of saltwater crustaceans range from 22 to 307 for whole body and from 5 to 25 for muscle (Tables 5b and 6b). Nimmo et al. (1977b) reported whole-body BCFs of 203 and 307 for two species of grass shrimp, *Palaemonetes pugio* and *P. vulgaris*. Vernberg et al. (1977) reported a factor of 140 for *P. pugio* at 25°C (Table 6b), whereas Pesch and Stewart (1980) reported a BCF of 22 for the same species exposed at 10°C, indicating that temperature might be an important variable. The commercially important crustaceans, the pink shrimp and lobster, were not effective bioaccumulators of cadmium with factors of 57 for whole body and 25 for muscle, respectively (Tables 5b and 6b).

Mallard ducks are a native wildlife species whose chronic sensitivity to cadmium has been studied. These birds can be expected to ingest many of the freshwater and saltwater plants and animals listed in Tables 4a and 4b. White and Finley (1978a,b) and White et al. (1978) found significant damage at a cadmium concentration of 200 mg/kg in food for 90 days. Di Giulio and Scanlon (1984) found significant effects on energy metabolism at 450 mg/kg, but not at 150 mg/kg. These are concentrations which would cause damage to mallard ducks. More recent information may be available, but these data would not have been identified during the literature search conducted for this update.

The bioaccumulation data provided in this document is for information purposes only. Calculation of a Final Residue Value for cadmium will not be presented at this time.

OTHER DATA

Data presented in Table 6 are not acceptable for inclusion in Tables 1-5, but provide useful information on the effects of cadmium to aquatic organisms. Several studies were reported in Table 6 and not in Table 1 either because the organisms were fed during acute studies (Lewis and Horning 1991; Ingersoll and Winner 1982; Mount and Norberg 1984; Pascoe et al. 1986; Schubauer-Berigan et al. 1993; Williams and Dusenbery 1990; Wiliams et al. 1986; Winner 1984) or the tests used unusual or uncharacterized dilution water (Hall et al. 1986; Hickey and Vickers 1992; Khangarot and Ray 1989a).

Although a number of the values in Tables 6a and 6b have already been discussed, the following section presents information supporting data presented in Tables 1-5, plus other useful trends or relationships. The effects of prior cadmium exposure to the resistence of the marine copepod, *Acartia clausi*, was investigated by Moraitou-Apostolopoulou et al. (1979). They observed that an *A. clausi* population collected from a metal impacted area displayed a greater tolerance to lethal cadmium concentrations when compared to a population obtained from a non-polluted site. The pollution acclimated population also had greater longevity than the non-adapted population when exposed to sublethal levels of cadmium.

The cumulative mortality resulting from exposure to cadmium for more than 96 hours is clearly evident from the studies with phytoplankton (Fargasova 1993; Findlay et al. 1996), duckweed (Outridge

1992), protozoa (Niederlehner et al. 1985), zooplankton (Lawrence and Holoka (1987), snails (Spehar et al. 1978), zebra mussels (Kraak et al. 1992a,b), crayfish (Thorp et al. 1979), macroinvertebrates (Giesy et al. 1979), polychaetes (Reish et al. 1976), bivalve molluscs, crabs, and starfish (Eisler and Hennekey 1977), scallops, shrimp, and crabs (Pesch and Stewart 1980), and a mysid (Gentile et al. 1982; Nimmo et al. 1977a).

In unmeasured flow-through sockeye salmon cadmium exposures, Servizi and Martens (1978) reported 7-day LC50 values that ranged from 8 to 4,500 μg/L for fry and alevins, respectively. The range and life stage sensitivity pattern observed by the authors were similar to other salmonid studies reported in Table 1a.

Nimmo et al. (1977a) in studies with the mysid, *Americamysis bahia*, reported a 96-hr LC50 of 15.5 μg/L (Table 1) and a 17-day LC50 of 11 μg/L (Table 6) at 25 to 28°C and salinity of 10 to 17 g/kg in the 96-hr study and 15 to 23 g/kg in the 17-day study. In another series of studies with this mysid (Gentile et al. 1982), the 96-hr LC50 was 110 μg/L (Table 1) and the 16-day LC50 was 28 μg/L (Table 6b) at 20°C and salinity of 30 g/kg. These data suggest that short-term acute toxicity might be strongly influenced by environmental variables, whereas long-term effects, even mortality, are not.

Considerable information exists concerning the effect of salinity and temperature on the acute toxicity of cadmium. Unfortunately, the conditions and durations of exposure are so different that adjustment of acute toxicity data for salinity is not possible. Rosenberg and Costlow (1976) studied the synergistic effects of cadmium and salinity combined with constant and cycling temperatures on the larval development of two estuarine crab species. They reported reduction in survival and significant delay in development of the blue crab with decreasing salinity. Cadmium was three times as toxic at a salinity of 10 g/kg than at 30 g/kg. Studies with the mud crab resulted in a similar cadmium-salinity response. In addition, the authors report that cycling temperature may have a stimulating effect on survival of larvae compared to constant temperature.

Theede et al. (1979) investigated the effect of temperature and salinity on the acute toxicity of cadmium to the colonial hydroid, *Laomedea loveni*. At 17.5 °C cadmium concentrations inducing irreversible retraction of half of the polyps ranged from 12.4 μg/L at a salinity of 25 g/kg to 3.0 μg/L at 10 g/kg (Table 6). At a temperature of 17.5°C, the toxicity of cadmium increased as salinity decreased from 25 g/kg to 10 g/kg.

A similar acute toxicity-salinity relationship was observed by Hall et al. (1995) for the copepod, *Eurytemora affinis*, whereby the 96-hour toxicity increased four-fold (from 213 to 51.6 μg/L cadmium) when the salinity was decreased from 15 to 5 g/kg at a test temperature of 25°C. Hall et al. (1995) also observed an approximate three-fold toxicity increase to the sheepshead minnow when the salinity was lowered in similar fashion at the same temperature. Likewise, the 21-day toxicity of cadmium to the blue crab, *Callinectes sapidus*, increased over nine-fold when the salinity was lowered from 25 to 2.5 g/kg, and the temperature was held constant at 22-23°C (Guerin and Stickle 1995). In contrast, Snell and Personne (1989b) observed little difference in the 24-hour toxicity of cadmium to the rotifer, *Brachionus plicatilis*, exposed under 15 and 30 g/kg salinity regimes and a temperature of 25°C.

The effect of environmental factors on the acute toxicity of cadmium is also evident from tests with the early life stages of saltwater vertebrates. Alderdice et al. (1979a,b,c) reported that salinity influenced the effects of cadmium on the volume, capsule strength, and osmotic response of embryos of the Pacific herring. Studies with embryos of the winter flounder indicated a quadratic salinity-cadmium relationship (Voyer et al. 1977), whereas Voyer et al. (1979) reported a linear relationship between salinity and cadmium toxicity to Atlantic silverside embryos.

Several studies have reported chronic sublethal effects of cadmium on saltwater fishes (Table 6b). Significant reduction in gill tissue respiratory rate was reported for the cunner after a 30-day exposure to 50 μg/L (MacInnes et al. 1977). Dawson et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 0.5 μg/L above ambient levels after a 30-day, but not a 90-day, exposure. A similar study with the winter flounder (Calabrese et al. 1975) demonstrated a significant alteration in gill tissue respiration rate measured *in vitro* after a 60-day exposure to 5 μg/L.

UNUSED DATA

Based on the requirements set forth in the guidelines (Stephen et al. 1985), the following studies are not acceptable for the following reasons and are classified as unused data.

Studies Were Conducted with Species That Are Not Resident in North America

Abbasi and Soni (1986)
Abel and Papoutsoglou (1986)
Abel and Garner (1986)
Abel and Barlocher (1988)
Ahsanullah et al. (1981)
Ahsanullah and Williams (1991)
Amiard-Triquet et al. (1987)
Annune et al. (1994)
Arshaduddin et al. (1989)
Austen et al. (1997)
Avery et al. (1996)
Azeez and Banerjee (1987)
Baby and Menon (1987)
Bambang et al. (1994)
Bednarz and Warkowska-Dratnal (1983/1984)
Birmelin et al. (1995)
Bresler and Yanko (1995)
Brooks et al. (1996)
Brunetti et al. (1991)
Calevro et al. (1998)

Canli and Furness (1993, 1995)
Cassini et al. (1986)
Castille and Lawrence (1981)
Centeno et al. (1993)
Chan (1988)
Chandini (1988, 1988, 1989, 1991)
Chandra and Garg (1992)
Charpentier et al. (1987)
Chattopadhyay et al. (1995)
Cheung and Lam (1998)
Coppellotti (1994)
D'Agostino and Finney (1974)
Dallinger et al. (1989)
Darmono (1990)
Darmono et al. (1990)
Datta et al. (1987)
Demon et al. (1989)
Den Besten et al. (1989, 1991)
De Nicola Giudici and Guarino (1989)
De Nicola Giudici and Migliore (1988)
Denton and Burdon-Jones (1986 1986)
Devi (1987, 1996)
Devi and Rao (1989)
Devineau and Triquet (1985)
Dorgelo et al. (1995)
Douben (1989)
Drbal et al. (1985)
Duquesne and Coll (1995)
Evtushenko et al. (1986)
Evtushenko et al. (1990)
Ferrari et al. (1993)
Fisher et al. (1996)
Fisher et al. (1996)
Forget et al. (1998)
Francesconi (1989)
Francesconi et al. (1994)
Forbes (1991)
Gaur et al. (1994)
Gerhardt (1992, 1995)

Ghosh and Chakrabarti (1990)
Glynn (1996)
Glynn et al. (1992, 1994)
Gopal and Devi (1991)
Green et al. (1986)
Greenwood and Fielder (1983)
Gupta and Rajbanshi (1991)
Gupta et al. (1992)
Hader et al. (1997)
Hansten et al. (1996)
Heinis et al. (1990)
Herkovits and Coll (1993)
Hiraoka et al. (1985)
Hu et al. (1996)
Huebner and Pynnonen (1992)
Husaini et al. (1991)
Ikuta (1987)
Jenkins and Sanders (1985)
Karlsson-Norrgren and Runn (1985)
Kasuga (1980)
Keduo et al. (1987)
Khangarot and Ray. (1987)
Khristoforova et al. (1984)
Kobayashi (1971)
Krassoi and Julli (1994)
Krishnaja et al. (1987)
Kuhn and Pattard (1990)
Kuroshima (1987)
Kuroshima and Kimura (1990)
Kuroshima et al. (1993)
Lam (1996, 1996)
Lam et al. (1997)
Lee and Xu (1984)
Loumbourdis et al. (1999)
McCahon et al. (1988)
McCahon and Pascoe (1988, 1988, 1988)
McCahon et al. (1989)
McClurg (1984)

Ma et al. (1999)
Malea (1994)
Markich and Jeffree (1994, 1994)
Martinez et al. (1996)
Metayer et al. (1982)
Michibata et al. (1986)
Michibata et al. (1987)
Migliore and Giudici (1987)
Moller et al. (1994)
Mostafa and Khalil (1986)
Muino et al. (1990)
Musko et al. (1990)
Nakagawa and Ishio (1988, 1989)
Nassiri et al. (1997)
Negilski (1976)
Nir et al. (1990)
Noraho and Gaur (1995)
Notenboom et al. (1992)
Nott and Nicolaidou (1994)
Nugegoda and Rainbow (1995)
Ojaveer et al. (1980)
Pantani et al. (1997)
Papathanassiou (1995)
Pavicic et al. (1994)
Perez-Coll and Herkovits (1996)
Pynnonen (1995)
Rainbow and Kwan (1995)
Rainbow et al. (1980)
Rainbow and White (1989)
Ralph and Burchett (1998)
Ramachandran et al. (1997)
Rao and Madhyastha (1987)
Rebhun and Ben-Amotz (1984)
Reish et al. (1988)
Ringwood (1990, 1992)
Ritterhoff et al. (1996)
Romeo and Gnassia-Barelli (1995)
Safadi (1998)
Sastry and Shukla (1994)

Sastry and Sunita (1982)
Saxena et al. (1990, 1993)
Schafer et al. (1994)
Sehgal and Saxena (1987)
Shanmukhappa and Neelakantan (1990)
Shivaraj and Patil (1988)
Simoes Goncalves (1989)
Stuhlbacher and Maltby (1992)
Takamura et al. (1989)
Temara et al. (1996a,b)
Ten Hoopen et al. (1985)
Thaker and Haritos (1989)
Thebault et al. (1996)
Theede et al. (1979)
Tomasik et al. (1995)
Tyurin and Khristoforova (1993)
Udoidiong and Akpan (1991)
Valencia et al. (1998)
Van Gemert (1985)
Vashchenko and Zhadan (1993)
Verriopoulos and Moraitou-Apostolopoulou (1981, 1982)
Visviki and Rachlin (1991)
Vogiatzis and Loumbourdis (1998)
Vranken et al. (1985)
Vuori (1994)
Vymazal (1990, 1995)
Walsh et al. (1995)
Warnau et al. (1995a,b,c, 1996a,b, 1997)
Westernhagen and Dethlefsen (1975)
Westernhagen et al. (1975, 1978)
Wildgust and Jones (1998)
White and Rainbow (1986)
Wicklund and Runn (1988)
Wicklund et al. (1988)
Wu et al. (1997)
Wundram et al. (1996)
Zanders and Rojas (1992, 1996)
Zou and Bu (1994)

Brown and Ahsanullah (1971) conducted tests with a brine shrimp species, that are too atypical to be used in deriving national criteria.

Cadmium Was a Component of a Drilling Mud, Effluent, Mixture, Sediment or Sludge

Allen (1994, 1995)
Amiard-Triquet et al. (1988)
Andres et al. (1999)
Arnac and Lassus (1985)
Austen and McEvoy (1997)
Bartsch et al. (1999)
Beiras et al. (1998)
Bendell-Young (1994)
Bendell-Young et al. (1986)
Besser and Rabeni (1987)
Biesinger et al. (1986)
Bigelow and Lasenby (1991)
Bodar et al. (1990)
Buckley et al. (1985)
Burden and Bird (1994)
Busch et al. (1998)
Campbell and Evans (1991)
Camusso et al. (1995)
Carlisle and Clements (1999)
Casini and Depledge (1997)
Cuvin-Aralar (1994)
Cuvin-Aralar and Aralar (1993)
Dallinger et al. (1997)
de March (1988)
Elliott et al. (1986)
Farag et al. (1994, 1998)
Gully and Mason (1993)
Hall et al. (1984, 1987, 1988)
Hardy and Raber (1985)
Hare et al. 1991, (1994)
Haritonidis et al. (1994)
Hartwell (1997)
Haynes et al. (1989)
Hendriks (1995)
Hickey and Clements (1998)
Hickey and Martin (1995)
Hickey and Roper (1992)
Hogstrand et al. (1991)
Hollis et al. (1996)
Hooten and Carr (1998)
Hylland et al. (1996)
Inza et al. (1998)
Jak et al. (1996)
Janssens de Bisthoven et al. (1992)
Jop (1991)
Keenan and Alikhan (1991)
Kelly and Whitton (1989)
Kettle and deNoyelles (1986)
Khan and Weis (1993)
Khan et al. (1989)
Kiffney and Clements (1996)

Klerks and Bartholomew (1991)
Kock et al. (1995)
Koivisto et al. (1997)
Kolok et al. (1998)
Kraak et al. (1993, 1994)
Krantzberg (1989a,b)
Krantzberg and Stokes (1988, 1989)
Kumar (1991)
Lee and Luoma (1998)
Lithner et al. (1995)
Lucker et al. (1997)
Macdonald and Sprague (1988)
Maloney (1996)
Manz et al. (1994)
Marr et al. (1995a, b)
Mathew and Menon (1992)
Mersch et al. (1996)
Nalewajko (1995)
Nelson (1994)
Odin et al. (1996, 1997)
Palawski et al. (1985)
Pedersen and Petersen (1996)
Pellegrini et al. (1993)
Playle et al. (1993)
Polar and Kucukcezzar (1986)
Poulton et al. (1995)
Prevot and Soyer-Gobillard (1986)
Qichen et al. (1988)
Rachlin and Grosso (1993)
Reynoldson et al. (1996)
Richelle et al. (1995)
Roch and McCarter (1984)
Roesijadi and Fellingham (1987)
Sanchiz et al. (1999)
Schaeffer et al. (1991)
Smokorowski et al. (1997)
Stephenson and Macki (1989)
Stern and Stern (1980)
Talbot (1985, 1987)
Tessier et al. (1993)
Vuori (1993)
Vymazal (1984)
Wall et al. (1996)
Walsh and Hunter (1992)
Wang et al. (1996)
Warren et al. (1998)
Weimin et al. (1994)
Wong et al. (1982)
Woodling (1993)
Woodward et al. (1995)

These Reviews Only Contain Data That Have Been Published Elsewhere

Barnthouse et al. (1987)
Bay et al. (1993)
Cairns et al. (1985)
Chapman et al. (1968)
Dierickx and Bredael-Rozen (1996)
Dyer et al. (1997)
Eisler (1981)
Bisler et al. (1979)
Enserink et al. (1991)
Florence et al. (1992)
Guilhermino et al. (1997)
Hare (1992)
Hornstrom (1990)
Jonnalagadda and Rao (1993)
Khangarot and Ray (1987)
Kooijman and Bedaux (1996)
Kraak et al. (1994a,b)
LeBlanc (1984)
Mark and Solbe (1998)
Meyer (1999)
Nendza et al. (1997)
Oikari et al. (1992)
Papoutsoglou and Abel (1993)
Pesonen and Andersson (1997)
Phillips and Russo (1978)
Ramesha et al. (1996)
Rice (1984)
Skowronski et al. (1998)
Spry and Wiener (1991)
Thomann et al. (1997)
Thompson et al. (1972)
Toussaint et al. (1995)
Trevors et al. (1986)
Van Leeuwen et al. (1987)
Vymazal (1990)
Wright and Welbourn (1994)
Wong (1987)

Organisms Were Exposed to Cadmium in Food or by Injection or Gavage

Bodar et al. (1988)
Brouwer et al. (1992)
Chou et al. (1986)
Davies et al. (1997)
Decho and Luoma (1994)
Gottofrey and Tjalve (1991)
Handy (1993)
Kluttgen and Ratte (1994)
Kuroshima (1992)
Lasenby and Van Duyn (1992)
Lawrence and Holoka (1991)
Lomagin and Ul'yanova (1993)
Malley and Chang (1991)
Melgar et al. (1997)
Mount et al. (1994)
Munger and Hare (1997)
Postma et al. (1994)
Postma and Davids (1995)
Reinfelder and Fisher (1994, 1994)
Reddy et al. (1997)
Rhodes et al. (1985)
Van den Hurk et al. (1998)
Wallace and Lopez (1997)
Wang and Fisher (1996)
Wen-Xiong and Fisher (1996)
Wong (1989)

No Interpretable Concentration, Time, Response Data or Examined Only a Single Concentration

Berglind (1985)
Bitton et al. (1994)
Block and Part (1992)
Block et al. (1991)
Blondin et al. (1989)
Bowen and Engel (1996)
Bressan and Brunetti (1988)
Castano et al. (1996)
Christoffers and Ernst (1983)
Clausen et al. (1993)
Fargasova (1994)
Fernandez-Pinas et al. (1995)
George et al. (1983)
Iftode et al. (1985)
Ilangovan et al. (1998)
Issa et al. (1995)
Jana and Sahana (1988)
Kluytmans et al. (1988)
Kraak et al. (1993b)
Kosakowska et al. (1988)
Lussier et al. (1999)
Mateo et al. (1993)
Palackova et al. (1994)
Pereira et al. (1993)
Prasad et al. (1998)
Rachlin and Grosso (1991)
Reader et al. (1989)
Reddy and Fingerman (1994)
Reid and McDonald (1991)
Ribo (1997),
Rombough (1985)
Rosas and Ramirez (1993)
Sauvant et al. (1997)
Skowronski et al. (1991)
Sunila and Lindstrom (1985)
Trehan and Maneesha (1994)
Verbost et al. (1987)
Visviki and Rachlin (1994)
Wang et al. (1995)
Woodall et al. (1988)
Wundram et al. (1996)
Xue and Sigg (1998)

No Useable Data on Cadmium Toxicity or Bioconcentration

Battaglini et al. (1993)
Borchardt (1983)
Craig et al. (1998)
Gargiulo et al. (1996)
Gomot (1998)
Harvey and Luoma (1985)
Kraal et al. (1995)
Penttinen et al. (1995)
Rouleau et al. (1998)
Sobhan and Sternberg (1999)

Organisms Were Selected, Adapted or Acclimated for Increased Resistance to Cadmium

Anadu et al. (1989)
Bodar et al. (1990)
Currie et al. (1998)
Ramo et al. (1987)
Herkovits and Perez-Coll (1995)
Kaplan et al. (1995)
McNicol and Scherer (1993)
Madoni et al. (1994)
Nagel and Voigt (1995)
Thomas et al. (1985)
Van Steveninck et al. (1992)

Data were not used if the results were only presented graphically (Laegreild et al. 1983; Laube 1980; Remacle et al. 1982), if the organisms were not exposed to cadmium in water (Foster 1982; Hatakeyama and Yasuno 1981a; O'Neill 1981), or if there was no pertinent adverse effect (Carr and Neff 1982; DeFilippis et al. 1981; Dickson et al. 1982; Fisher and Fabris 1982; Fisher and Jones 1981; Tucker and Matte 1980; Watling 1981; Weis et al. 1981).

Either the Materials, Methods or Results Were Insufficiently Described

Abbasi and Soni (1989)
Ball (1967)
Belabed et al. (1994)
Bendell-Young (1999)
Bitton et al. (1995)
Bjerregaard and Depledge (1994)
Bolanos et al. (1992)
Burnison et al. (1975)
Calevro et al. (1998)
Canton and Slooff (1979)
Carpene and Boni (1992)
D'Aniello et al. (1990)
Davies et al. (1994)
Department of the Environment (1973)
Errecalde et al. (1998)
Fennikoh et al. (1978)
Fernandez-Leborans and Antonio-Garcia (1988)
Galic and Sipos (1987)
Glubokov (1990)
Gorman and Skogerboe (1987)
Guanzon et al. (1994)
Guerin et al. (1994)
Hofslagare et al. (1985)
Janssen and Persoone (1993)
Jaworska et al. (1997)
Kay et al. (1986)
Kessler (1985)
Khangarot et al. (1987)
Koyama et al. (1992)
Landner and Jernelov (1969)
Lee and Oshima (1998)
Liao and Hsieh (1990)
Maas (1978)
Mansour (1993)
Ministry of Technology (1967)
Moza et al. (1995)
Munger et al. (1999)
Naylor et al. (1992)
Nwadukwe and Erondu (1996)
Pascoe and Shazili (1986)
Pauli and Berger (1997)
Penttinen et al. (1998)
Peterson (1991)
Peterson et al. (1984)
Rayms-Keller et al. (1998)
Rombough (1985)
Sandau et al. (1996)
Sekkat et al. (1992)
Shcherban (1977)
Sheela et al. (1995)
Sovenyi and Szakolczai (1993)
Stom and Zubareva (1994)
Stubblefield et al. (1999)
Tarzwell and Henderson (1960)
Verma et al. (1980)
Vykusova and Svobodova (1987)
Wani (1986)
Witeska et al. (1995)
Yamamoto and Inque (1985)
Zhang et al. (1992)

High control mortalities occurred in testing reported by Asato and Reish (1988), Hong and Reish (1987), Sauter et al. (1976) and Wright (1988). The 96-hr values reported by Buikema et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema et al. 1977). Bringmann and Kuhn (1982) and Dave et al. (1981) cultured daphnids in one water and tested them in a different water. The acceptability of the dilution water or medium used in some studies (e.g., Brkovic-Popovic and Popovic 1977a,b; Cearley and Coleman 1973, 1974; Nasu et al. 1983) was open to question because of its origin or content.

Inappropriate Medium or Medium Contained Too Much of a Complexing Agent for Algal Studies

Baillieul and Blust (1999)
Brand et al. (1986)
Chen et al. (1997)
Couillard (1989)
Hockett and Mount (1996)
Huebert et al. (1993)
Huebert and Shay (1991, 1992, 1993)
Jenkins and Mason (1988)
Jenkins and Sanders (1986)
Jenner and Janssen-Mommen (1993)
Kessler (1986)
Lue-Kim et al. (1980)
Macfie et al. (1994)
Meteyer et al. (1988)
Muller and Payer (1979)
Nasu et al. (1988)
Rebhun and Ben-Amotz (1986, 1988)
Stary and Kratzer (1982)
Stary et al. (1983)
Sloof et al. (1995)
Sunda and Huntsman (1996)
Thongra-ar and Matsuda (1993)
Thorpe and Costlow (1989)
Tortell and Price (1996)
Vasseur and Pandard (1988)
Wright et al. (1985)

Questionable Treatment of Test Organisms or Inappropriate Test Conditions or Methodology

Babich and Stotsky (1982)
Brown et al. (1984)
Bryan (1971)
Chan et al. (1981)
Dorfman (1977)
Eisler and Gardner (1973)
Greig (1979)
Hung (1982)
Hutcheson (1975)
Moraitou-Apostolopoulou et al. (1979)
Parker (1984)
Pecon and Powell (1981)
Rehwoldt et al. (1972, 1973)
Ridlington et al. (1981)
Servizi and Martens (1978)
Sunda et al. (1978)
Wikfors and Ukeles (1982)

Bioconcentration Studies Conducted in Distilled Water, Not Conducted Long Enough, Not Flow-through or Water Concentrations Not Adequately Measured

Allen (1995)
Amiard et al. (1993)
Amiard-Triquet et al. (1986)
Balogh and Salanki (1984)
Baudrimont et al. (1997)
Beattie and Pascoe (1978)
Bentley (1991)
Berglind (1986)
Bernds (1998)
Bervoets et al. (1995, 1996)
Bjerregaard (1982, 1985, 1991)
Block and Glynn (1992)

Brown et al. (1986)
Burrell and Weihs (1983)
Carmichael and Fowler (1981)
Carr and Neff (1982)
Chan et al. (1992)
Chander et al. (1991)
Chawla et al. (1991)
Chitguppa et al. (1997)
Chou and Uthe (1991)
Collard and Matagne (1994)
Craig et al. (1999)
Davies et al. (1981)
De Conto Cinier et al. (1997)
De Conto Cinier et al. (1998)
De Nicola et al. (1993)
Denton and Burdon-Jones (1981)
Elliott et al. (1985)
Engel (1999)
Everaarts (1990)
Fair and Sick (1983)
Frazier and George (1983)
Freeman (1978, 1980)
Giles (1988)
Gottofrey et al. (1988)
Graney et al. (1984)
Gupta and Devi (1993)
Haines and Brumbaugh (1994)
Hansen et al. (1995)
Hardy and O'Keeffe (1985)
Hashim et al. (1997)
Hatakeyama (1987)
Herwig et al. (1989)
Hollis et al. (1997)
Irato and Piccinni (1996)
John et al. (1987)
Katti and Sathyanesan (1985)
Kerfoot and Jacobs (1976)
Khoshmanesh et al. (1996, 1997)
Klaverkamp and Duncan (1987)
Koelmans et al. (1996)
Kohler and Riisgard (1982)
Kwan and Smith (1991)
Langston and Zhou (1987)
Les and Walker (1984)
McLeese and Ray (1984)
Maeda et al. (1990)
Malley et al. (1989)
Maranhao et al. (1999)
Mersch et al. (1993)
Mizutani et al. (1991)
Muramoto (1980)
Mwangi and Alikhan (1993)
Nolan and Duke (1983)
Norey et al. (1990)
Oakley et al. (1983)
Olesen and Weeks (1994)
Papathanassiou (1986)
Pawlik and Skowronski (1994)
Pawlik et al. (1993)
Pelgrom et al. (1994)
Pelgrom et al. (1997)
Playle and Dixon (1993)
Presing et al. (1993)
Postma et al. (1996)
Poulsen et al. (1982)
Rai et al. 1995
Rainbow (1985)
Ramirez et al. (1989)
Ray et al. (1981)
Reichert et al. (1979)
Reinfelder et al. (1997)
Riisgard et al. (1987)
Ringwood (1989, 1992, 1993)
Roseman et al. (1994)
Rubinstein et al. (1983)
Santojanni et al. (1998)
Sedlacek et al. (1989)
Sidoumou et al. (1997)
Simoes Goncalves et al. (1988)
Sinha et al. (1994)
Skowronski and Przytocka-Jusiak (1986)
Srivastava and Appenroth (1995)
Stary et al. (1982)
Sunil et al. (1995)
Suzuki et al. (1987)
Swinehart (1990)
Taylor et al. (1988)
Tessier et al. (1996)
Thomas et al. (1983)
Van Leeuwen et al. (1985)
Van Ginneken et al. (1999)
Vymazal (1995)
Wang and Fisher (1998)
Watling (1983a)
White and Rainbow (1982)
Williams et al. (1998)
Windom et al. (1982)
Winner and Gauss (1986)
Winter (1996)
Woodworth and Pascoe (1983)
Xiaorong et al. (1997)
Yager and Harry (1964)
Zauke et al. (1995)
Zia and McDonald (1994)

The bioconcentration tests of Eisler (1974), Jennings and Rainbow (1979b), O'Hara (1973b), Phelps (1979), and Sick and Baptist (1979), which used radioactive isotopes of cadmium, were not used because of the possibility of isotope discrimination. Reports on the concentrations of cadmium in wild aquatic organisms, such as Anderson et al. (1978), Bouquegneau and Martoja (1982), Boyden (1977), Bryan et al. (1983), Frazier (1979), Gordon et al. (1980), Greig and Wenzloff (1978), Hazen and Kneip (1980), Kneip and Hazen (1979), McLeese et al. (1981), Noel-Lambot et al. (1980), Pennington et al. (1982), Ray et al. (1981), Smith et al. (1981), and Uthe et al. (1982) were not used for the calculation of bioaccumulation factors due to an insufficient number of measurements of the concentration of cadmium in the water.

SUMMARY

Freshwater Species Mean Acute Values (SMAV) for cadmium are available for species in 55 genera and hardness adjusted values range from 1.613 μg/L for brown trout to 96,880 μg/L for a midge. Freshwater invertebrate SMAVs range from 13.41 μg/L for *D. magna* to 96,880 μg/L for a midge and SMAVs for 24 fish species from 1.613 μg/L for the brown trout to 10,663 μg/L for the tilapia. The antagonistic effect of hardness on acute toxicity has been demonstrated with 12 species. Acceptable chronic tests have been conducted on cadmium with 14 freshwater fish species and seven invertebrate species with hardness adjusted Species Mean Chronic Values (SMCV) ranging from 0.2747 μg/L for *Hyalella azteca* to 27.17 μg/L for *Ceriodaphnia dubia*. Acute-chronic ratios are available for six species and range from 0.9021 for the chinook salmon to 433.8 for the flagfish.

Freshwater aquatic plants are affected by cadmium at concentrations ranging from 2 to 20,000 μg/L. These values are in the same range as the acute toxicity values for fish and invertebrate species, and are considerably above the chronic values. Bioconcentration factors (BCFs) for cadmium in freshwater range from 7 to 6,910 for invertebrates and from 3 to 2,213 for fishes.

Saltwater cadmium SMAVs are available for species in 54 genera and SMAVs for 50 species of invertebrates range from 41.29 μg/L for a mysid to 135,000 μg/L for an oligochaete worm. SMAVs for 11 fish species range from 75.0 μg/L for striped bass to 50,000 μg/L for sheepshead minnow. The acute toxicity of cadmium generally increases as salinity decreases. The effect of temperature seems to be species-specific. Chronic tests have been conducted with two mysid species, *Americamysis bahia* and *Mysidopsis bigelowi*, with SMCVs of 6.173 μg/L and 7.141 μg/L, respectively. Acute-chronic ratios are available for each species, 5.384 for *A. bahia* and 15.40 for *M. bigelowi*. The acute values appear to reflect effects of varying salinity and temperature levels, whereas the few available chronic values apparently do not.

Studies with macroalgae and microalgae revealed effects at 22.8 to 22,390 μg/L, respectively.

These values are in the same range as acute toxicity values for fish and invertebrate species, and are above the chronic values. BCFs determined with a variety of saltwater invertebrates range from 5 to 3,160. BCFs for bivalve molluscs were generally above 1,000 in long exposures, with no indication that steady-state had been reached.

A comparison of the criteria developed in this document with the previous National recommended water quality criteria (which is based on the 1995 update for freshwater and the 1984 update for saltwater) indicates that the updated 2001 freshwater CMC of 1.0 μg/L dissolved cadmium has remained approximately the same (the value was lowered each time to protect the commercially important rainbow trout), but the freshwater chronic CCC has been lowered to 0.15 μg/L dissolved cadmium in this document from 1.3 μg/L in the 1995 document. This 2001 update contains a database of 55 freshwater genera for acute toxicity (43 genera were in the 1995 update), and 15 genera for freshwater chronic toxicity (12 genera were provided in the 1995 document). As a result of the additional data, the acute and chronic hardness derived slopes are different in this update relative to previous versions. This update did not use an adjusted "n" value to calculate the Final Chronic Value (the 1995 update modified the total "n" for the chronic value to be the same as the acute "n" value). Included in this updated document are toxicity results for certain threatened and endangered species that were not available earlier. Saltwater cadmium criteria remained relatively the same between the 1999 National recommended water quality criteria and 2001 documents. The new saltwater CMC of 40 μg/L dissolved cadmium presented in this document is only slightly lower than the 42 μg/L cadmium found in the previous national recommended water quality criteria. The chronic CCC dropped slightly to 8.8 μg/L cadmium in this document from the 9.3 μg/L value previously recommended. There are 54 genera in the acute saltwater database of this document (the 1984 document had 33 genera), and the same two saltwater chronic genera are presented in both documents (a third *A. bahia* chronic value was added to this document).

NATIONAL CRITERIA

The available toxicity data, when evaluated using 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 unusually sensitive, freshwater aquatic life should be protected at a total hardness of 50 mg/L as $CaCO_3$ if the four-day average concentration (in μg/L) of dissolved cadmium does not exceed the numerical value given by

0.938 $[e^{(0.7409[\ln(\text{hardness})]-4.719)}]$ more than once every three years on the average, and if the 24-hour average dissolved concentration (in μg/L) does not exceed the numerical value given by 0.973 $[e^{(1.0166[\ln(\text{hardness})]-3.924)}]$ more than once every three years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the four-day average dissolved concentrations of cadmium are 0.15, 0.25 and 0.40 μg/L, respectively, and the 24-hour average dissolved concentrations are 1.0, 2.0, and 3.9 μg/L.

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 unusually sensitive, saltwater aquatic life should be protected if the four-day average dissolved concentration of cadmium does not exceed 8.8 μg/L more than once every three years on the average and if the 24-hour average dissolved concentration does not exceed 40 μg/L more than once every three years on the average. However, the limited data suggest that the acute toxicity of cadmium is salinity-dependent; therefore the 24-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

U.S. EPA believes that the use of dissolved cadmium will provide a more scientifically correct basis upon which to establish water-column criteria for metals. The criteria were developed on this basis. The use of dissolved criteria reduces the amount of conservatism that was present in earlier cadmium criteria. It is recognized that a considerable proportion of dissolved cadmium in organic-rich waters may be less toxic than freely dissolved cadmium. On the other hand, some particulate forms of cadmium might contribute to cadmium loading of organisms, possibly through ingestion.

A return interval of three years continues to be the Agency's general recommendation. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration (CMC) design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration (CCC) design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA 1991).

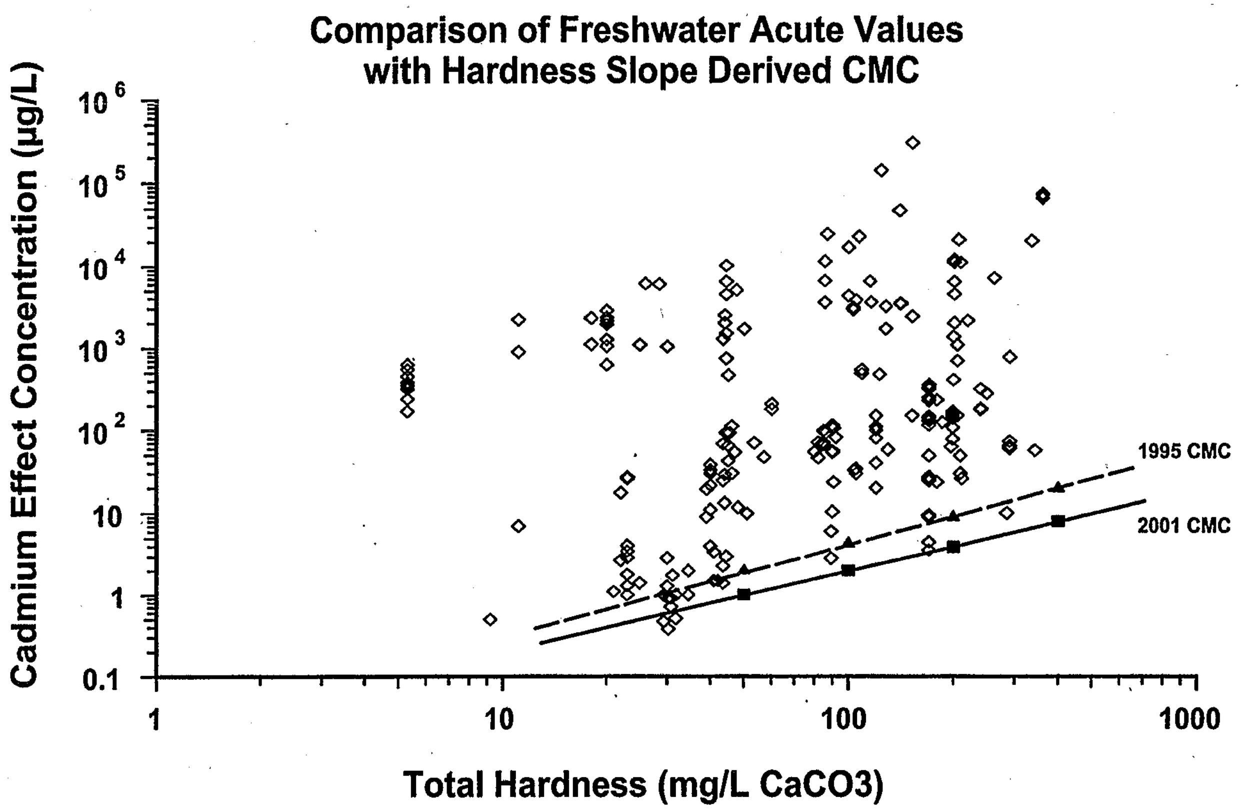

Figure 1. Comparison of All Table 1 Freshwater Acute Toxicity Test EC50s and LC50s with the Hardness Slope Derived CMC.
(2001 CMC: solid line; 1995 CMC: dashed line)

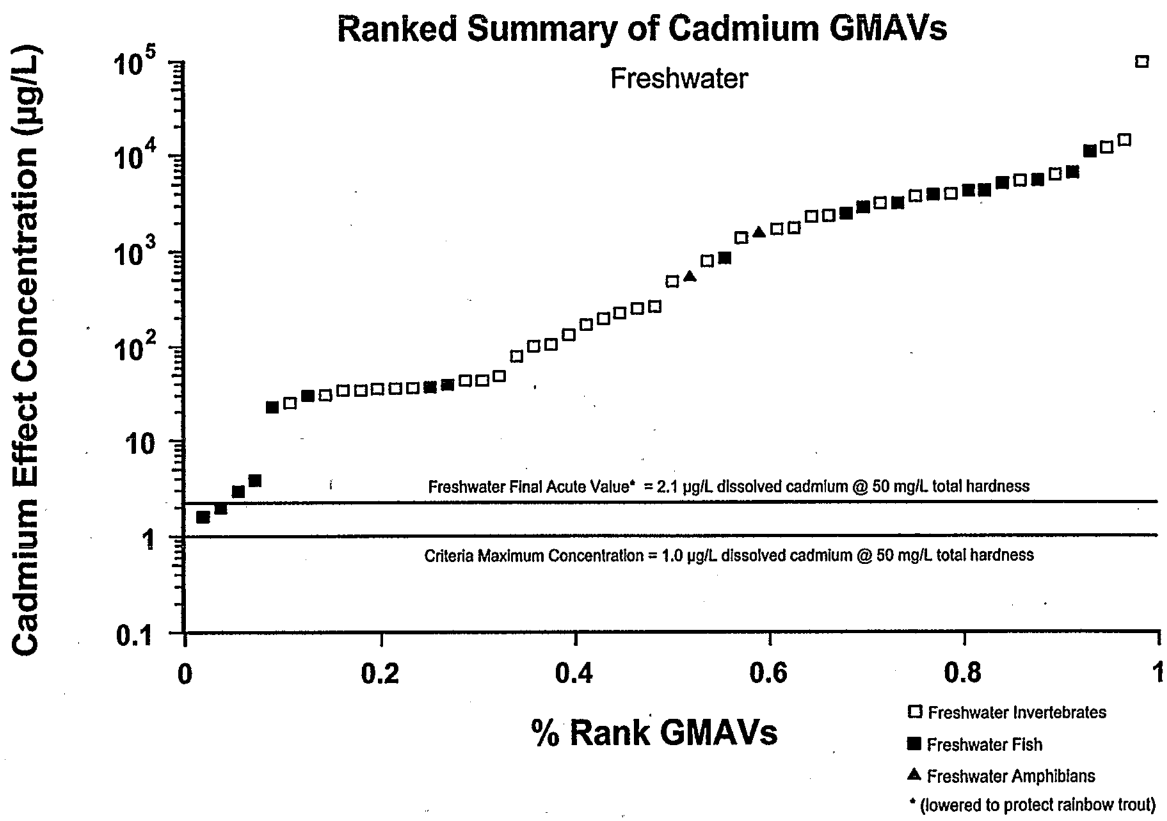

Figure 2. Ranked Summary of Cadmium GMAVs (Freshwater).

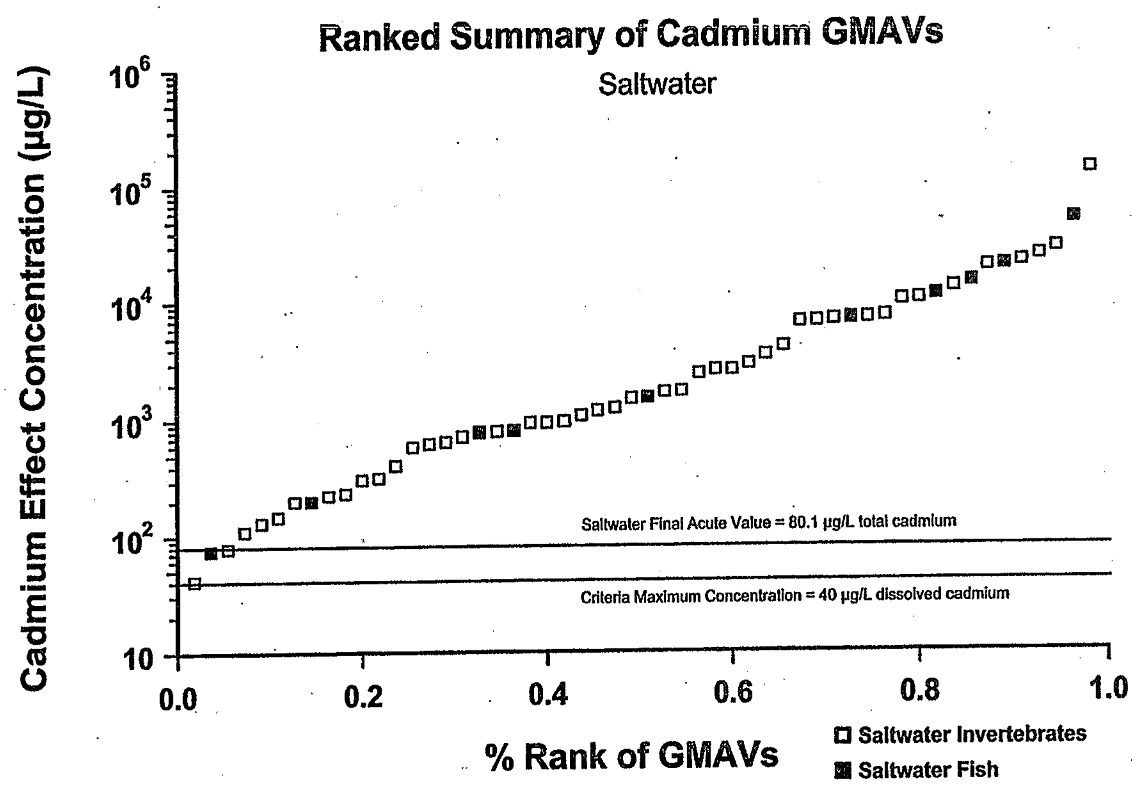

Figure 3. Ranked Summary of Cadmium GMAVs (Saltwater).

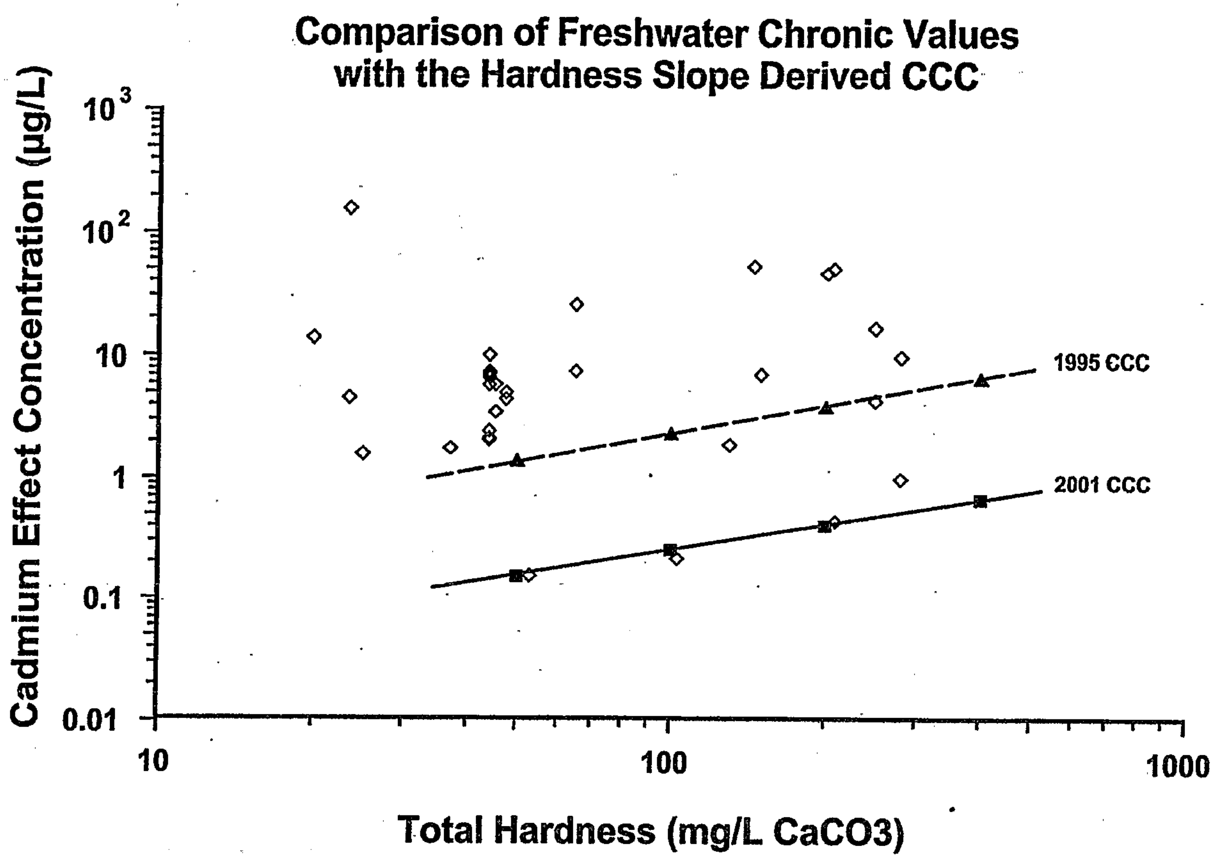

Figure 4. Comparison of All Table 2 Freshwater Chronic Values with the Hardness Slope Derived CCC. (2001 CCC: solid line; 1995 CCC: dashed line)

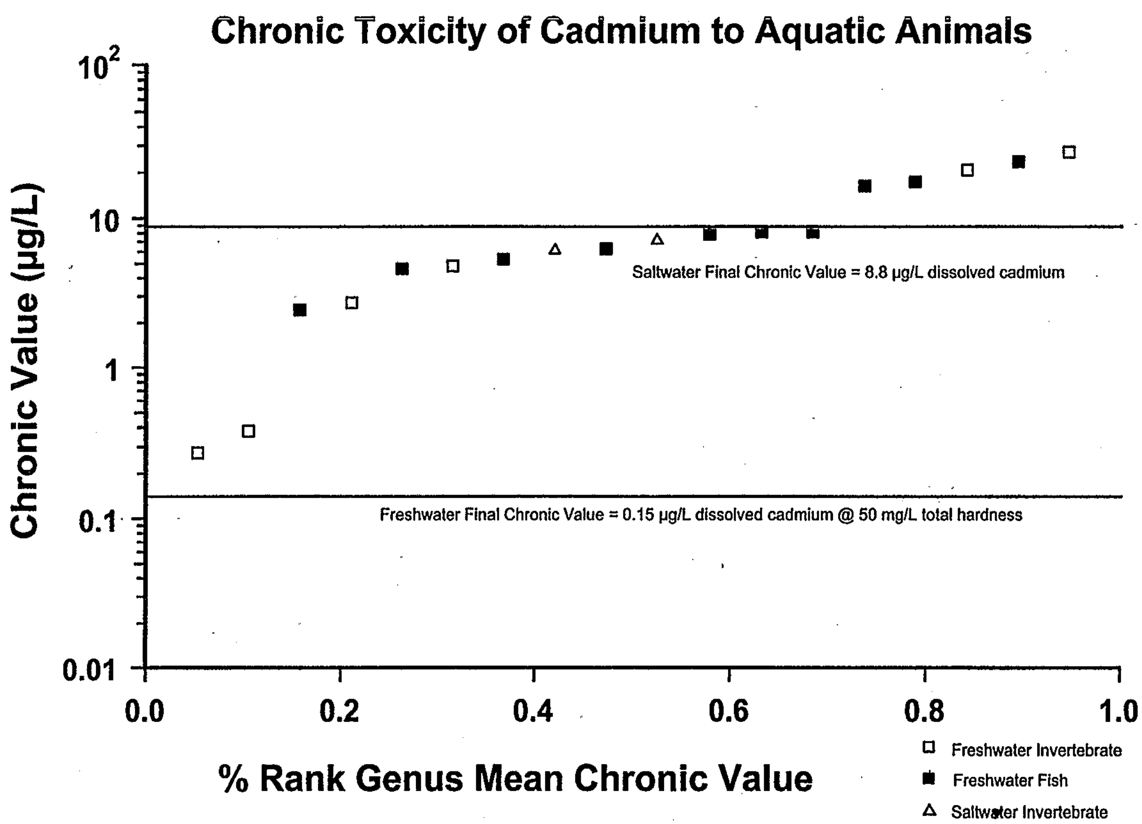

Figure 5. Chronic Toxicity of Cadmium to Aquatic Animals.

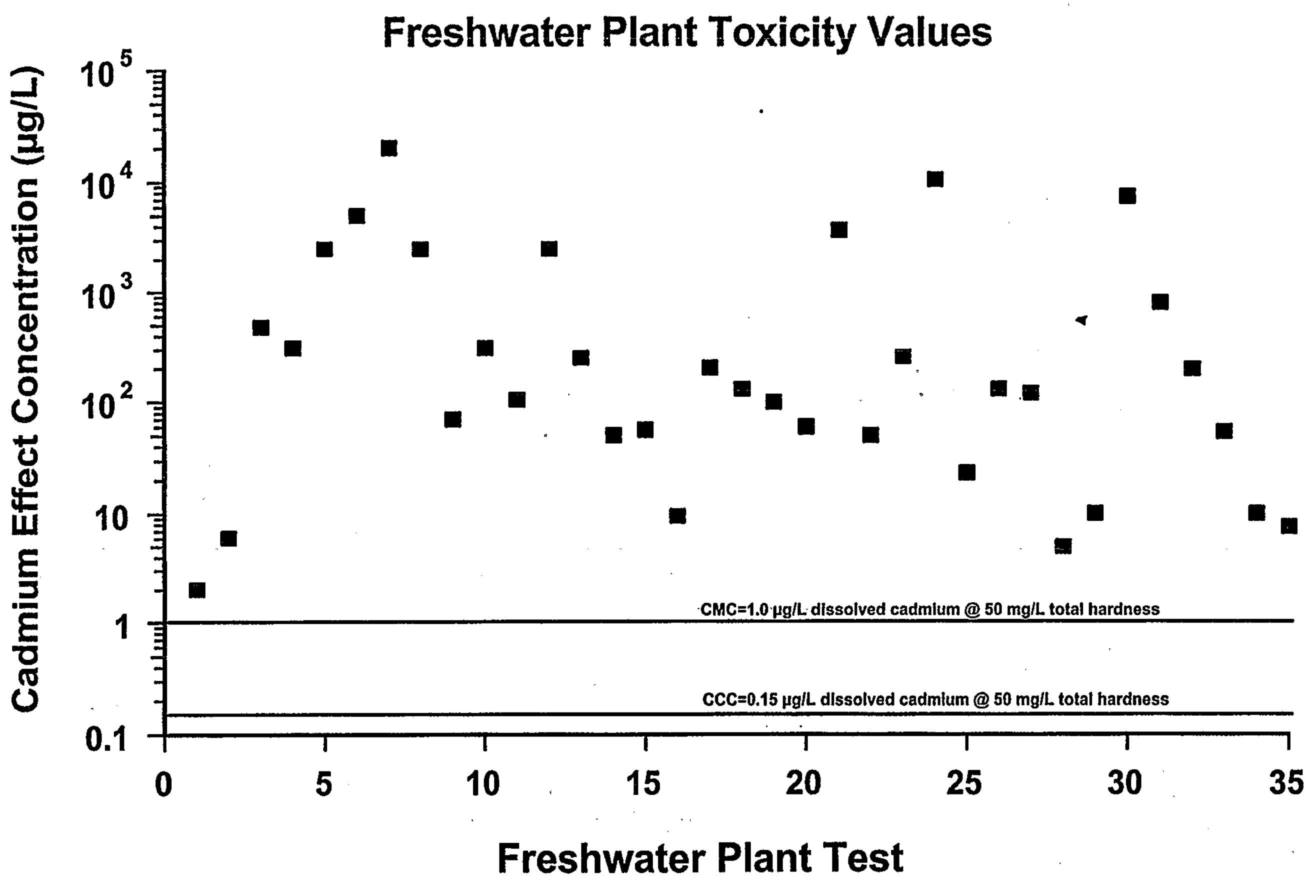

Figure 6. Comparison of Freshwater Plant Toxicity Values (Table 4) and Freshwater CMC and CCC Values.

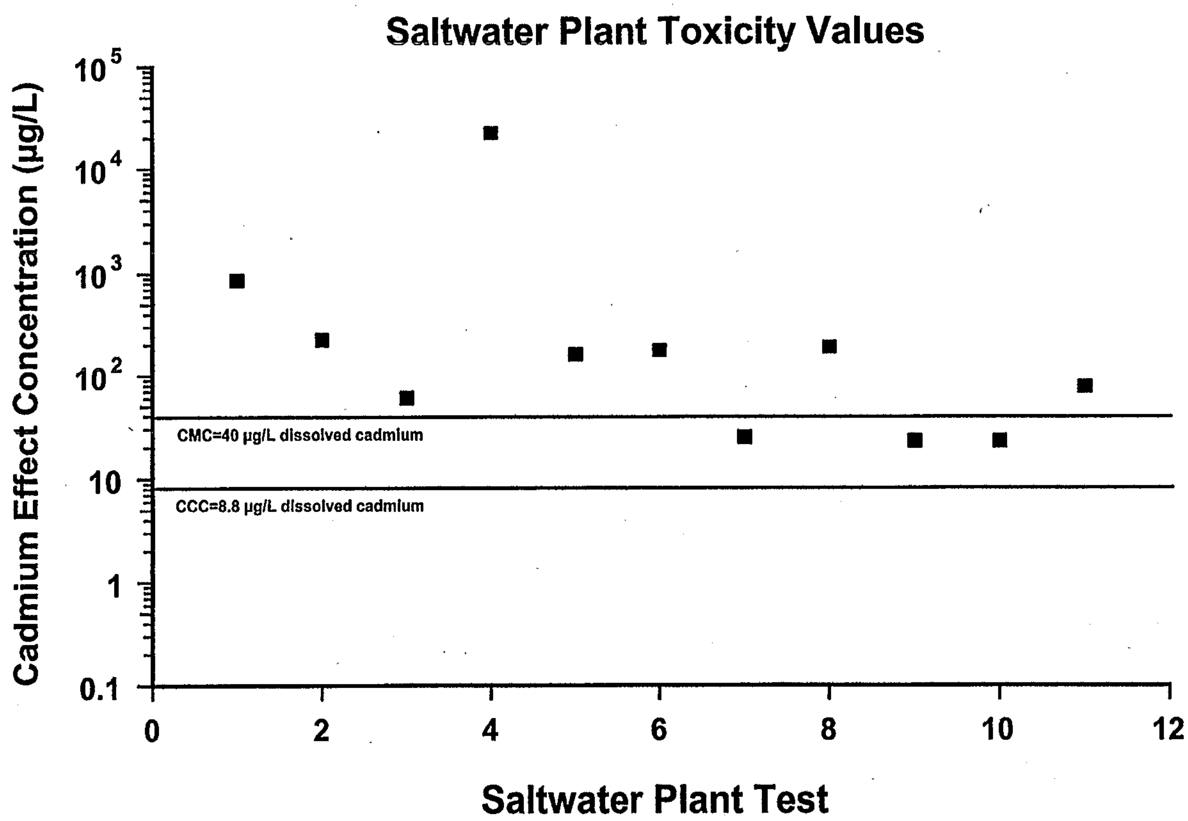

Figure 7. Comparison of Saltwater Plant Toxicity Values (Table 4) and Saltwater CMC and CCC Values.

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Planarian, *Dendrocoelum lacteum*	R, M, T	Cadmium chloride	87	24,702	23,220	14,067	14,067	Ham et al. 1995
Worm (adult), *Lumbriculus variegatus*	S, M, T	Cadmium nitrate	290 (280-300)	780	-	130.6	130.6	Schubauer-Berigan et al. 1993
Tubificid worm, *Branchiura sowerbyi*	S, M	Cadmium sulfate	5.3	240	-	2,350	2,350	Chapman et al. 1982
Tubificid worm, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	-	1,665	-	Chapman et al. 1982
Tubificid worm (30-40 mm) *Limnodrilus hoffmeisteri*	F, M, T	-	152	2,400	-	775.0	775.0	Williams et al. 1985
Tubificid worm, *Quistadrilus multisetosus*	S, M	Cadmium sulfate	5.3	320	-	3,133	3,133	Chapman et al. 1982
Tubificid worm, *Rhyacodrilus montana*	S, M	Cadmium sulfate	5.3	630	-	6,169	6,169	Chapman et al. 1982
Tubificid worm, *Spirosperma ferox*	S, M	Cadmium sulfate	5.3	350	-	3,427	3,427	Chapman et al. 1982
Tubificid worm, *Spirosperma nikolskyi*	S, M	Cadmium sulfate	5.3	450	-	4,406	4,406	Chapman et al. 1982
Tubificid worm, *Stylodrilus heringlianus*	S, M	Cadmium sulfate	5.3	550	-	5,386	5,386	Chapman et al. 1982
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	3,200	-	1,231	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	1,700	-	653.8	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	-	1,032	-	-	-	Fargasova 1994a
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	-	3,133	1,361	Chapman et al. 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Tubificid worm, *Varichaeta pacifica*	S, M	Cadmium sulfate	5.3	380	-	<u>3,721</u>	3,721	Chapman et al. 1982
Leech, *Glossiponia complanta*	R, M, T	Cadmium chloride	122.8	480	-	<u>192.5</u>	192.5	Brown and Pascoe 1988
Snail, *Aplexa hypnorum*	F, M	Cadmium chloride	45.3	93	-	<u>102.8</u>	-	Holcombe et al. 1984
Snail (adult), *Aplexa hypnorum*	F, M, T	Cadmium chloride	44.4	93	-	<u>104.9</u>	103.9	Phipps and Holcombe 1985
Snail (adult), *Physa gyrina*	S, M	-	200	1,370	-	334.7[d]	-	Wier and Walter 1976
Snail (immature), *Physa gyrina*	S, M	-	200	410	-	<u>100.2</u>	100.2	Wier and Walter 1976
Mussel (juvenil), *Actinonaia pectorosa*	S,M,T	-	82	46.4	-	<u>28.06</u>	-	Keller Unpublished
Mussel (juvenile), *Actinonaia pectorosa*	S,M,T	-	84	69	-	<u>40.72</u>	33.80	Keller Unpublished
Mussel (juvenile), *Lampsilis straminea claibornensis*	S,M,T	-	40	38	-	<u>47.68</u>	47.68	Keller Unpublished
Mussel, *Lampsilis teres*	S,M,T	-	40	11	-	<u>13.80</u>	-	Keller Unpublished
Mussel (juvenile), *Lampsilis teres*	S,M,T	-	40	33	-	<u>41.40</u>	23.90	Keller Unpublished
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	114.7	-	<u>63.10</u>	-	Keller Unpublished
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	111.8	-	<u>61.51</u>	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S,M,T	Cadmium chloride	92	81.9	-	<u>44.06</u>	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S,M,T	Cadmium chloride	86	93.0	-	<u>53.59</u>	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S, M, T	Cadmium chloride	39	9	-	<u>11.59</u>	-	Keller and Zam 1991

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Mussel (juvenile), *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	107	-	58.87	42.92	Keller and Zam 1991
Mussel, *Vilosa vibex*	S, M, T	-	40	30	-	37.64	-	Keller Unpublished
Mussel, *Vilosa vibex*	S, M, T	-	186	125	-	32.88	35.18	Keller Unpublished
Cladoceran, *Alona affinis*	S, U	Cadmium nitrate	109	546	-	247.2	247.2	Ghosh et al. 1990
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90 (80-100)	54	-	29.71	-	Bitton et al. 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M, T	Cadmium chloride	80 (70-90)	54.5	-	33.80	-	Diamond et al. 1997
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90 (80-100)	55.9	-	30.75	31.37	Lee et al. 1997
Cladoceran (<24 hr) *Ceriodaphnia reticulata*	S, U	Cadmium chloride	240	184	-	37.35	-	Elnabarawy et al. 1986
Cladoceran (<6 hr) *Ceriodaphnia reticulata*	S, U	Cadmium chloride	120	110	-	45.17	41.07	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	<1.6[h]	-	-	-	Anderson 1948
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	-	72.35	-	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	27.07	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	28.36	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	35.45	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	105	30	-	14.11	-	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	209.2	30	-	7.002	-	Canton and Slooff 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	-	8.213	-	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	-	16.43	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	-	36.13	-	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	3.6 (genotype A)	-	1.038	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-1)	-	2.594	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-2)	-	2.594	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	4.5 (genotype B)	-	1.297	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	27.1 (genotype E)	-	7.810	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	115.9 (genotype S-1)	-	33.40	-	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	24.5 (Clone F)	-	7.061	-	Stuhlbacher et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	129.4 (Clone S-1)	-	37.29	-	Stuhlbacher et al. 1992
Cladoceran (3 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	25.4 (Clone F)	-	7.320[f]	-	Stuhlbacher et al. 1993
Cladoceran (3 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	228.8 (Clone S-1)	-	65.94[f]	-	Stuhlbacher et al. 1993
Cladoceran (6 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	49.1 (Clone F)	-	14.15[f]	-	Stuhlbacher et al. 1993
Cladoceran (6 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	250.1 (Clone S-1)	-	72.08[f]	-	Stuhlbacher et al. 1993
Cladoceran (10 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	131.2 (Clone F)	-	37.81[f]	-	Stuhlbacher et al. 1993
Cladoceran (10 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	319.3 (Clone S-1)	-	92.02[f]	-	Stuhlbacher et al. 1993

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran (20 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	139.9 (Clone F)	-	40.32[f]	-	Stuhlbacher et al. 1993
Cladoceran (20 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	326.3 (Clone S-1)	-	94.04[f]	-	Stuhlbacher et al. 1993
Cladoceran (30 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	146.7 (Clone F)	-	42.28[f]	-	Stuhlbacher et al. 1993
Cladoceran (30 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	355.3 (Clone S-1)	-	102.4[f]	-	Stuhlbacher et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	360	-	-	-	Fargasova 1994a
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	-	<u>54.52</u>	-	Crisinel et al. 1994
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170 (160-180)	9.5	-	<u>2.738</u>	-	Guilhermino et al. 1996
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	112 (clone S-1)	104	<u>121.6</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	106 (clone S-1)	91.4	<u>57.86</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	233 (clone S-1)	179	<u>63.72</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	30.1 (clone A)	27.8	<u>32.69</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	23.4 (clone A)	20.2	<u>12.77</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	23.6 (clone A)	18.1	<u>6.454</u>	-	Barata et al. 1998
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	51	9.9	-	<u>9.703</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr) *Daphnia magna*	S, M, T	Cadmium Chloride	104	33	-	<u>15.67</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	105	34	-	<u>15.99</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	197	63	-	<u>15.63</u>	-	Chapman et al. Manuscript

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	209	49	-	**11.45**	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	F, M, T	Cadmium Chloride	130	58	-	**21.96**	13.41	Attar and Maly 1982
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium nitrate	-	90.23	-	-	-	Canton and Adema 1978
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	-	**41.14**	-	Bertram and Hart 1979
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	-	**64.75**	-	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	-	**32.85**	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	-	**41.07**	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	53.5	70.1	-	**65.44**	-	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	66	-	**38.48**	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	99	-	**57.72**	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	70	-	**40.82**	46.36	Roux et al. 1993
Cladoceran, *Moina macrocopa*	S, U	Cadmium chloride	82 (80-84)	71.25	-	**43.09**	43.09	Hatakeyama and Yasuno 1981b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	11.1	7.0	-	**32.33**	-	Giesy et al. 1977
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	43.5 (39-48)	24.5	-	**28.23**	30.21	Spehar and Carlson 1984a,b
Copepod, *Cyclops varicans*	S, U	Cadmium nitrate	109	493	-	**223.2**	223.2	Ghosh et al. 1990
Isopod, *Asellus bicrenata*	F, M	Cadmium chloride	220	2,129[g]	-	**472.1**	472.1	Bosnak and Morgan 1981

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Isopod, *Lirceus alabamae*	F, M	Cadmium chloride	152	150[g]	-	48.44	48.44	Bosnak and Morgan 1981
Amphipod (4 mm), *Crangonyx pseudogracilis*	R, U	Cadmium chloride	50	1,700	-	1,700	1,700	Martin and Holdich 1986
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	43.5 (39-48)	68.3	-	78.69	78.69	Spehar and Carlson 1984a,b
Crayfish (1.8 g), *Orconectes immunis*	F, M, T	Cadmium chloride	44.4	>10,200	-	>11,509	>11,509	Phipps and Holcombe 1985
Crayfish, *Orconectes limosus*	S, M	Cadmium chloride	-	400	-	-	-	Boutet and Chaisemartin 1973
Crayfish, *Orconectes virilis*	F, M, T	Cadmium chloride	26	6,100	-	11,859	11,859	Mirenda 1986
Crayfish (juvenile), *Procambarus clarkii*	S, M	Cadmium chloride	30	1,040	-	1,748	1,748	Naqvi and Howell 1993
Mayfly, *Ephemerella grandis*	F, M	Cadmium chloride	-	28,000	-	-	-	Clubb et al. 1975
Mayfly, *Ephemerella grandis*	S, U	Cadmium sulfate	44	2,000	-	2,278	2,278	Warnick and Bell 1969
Stonefly, *Pteronarcella badia*	F, M	Cadmium chloride	-	18,000	-	-	-	Clubb et al. 1975
Midge (4th instar), *Chironomus riparius*	R, M, T	Cadmium chloride	124	140,000	-	55,607	-	Pascoe et al. 1990
Midge (10-12 mm), *Chironomus riparius*	F, M, T	-	152	300,000	-	96,880	96,880	Williams et al. 1985
Bryozoan, *Pectinatella magnifica*	S, U	-	205 (190-220)	700	-	166.8	166.8	Pardue and Wood 1980
Bryozoan, *Lophopodella carteri*	S, U	-	205 (190-220)	150	-	35.74	35.74	Pardue and Wood 1980
Bryozoan, *Plumatella emarginata*	S, U	-	205 (190-220)	1,090	-	259.7	259.7	Pardue and Wood 1980
Coho salmon (1 year), *Oncorhynchus kisutch*	S, U	Cadmium chloride	90	10.4	-	5.722	-	Lorz et al. 1978

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Coho salmon (juvenile), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	3.4	-	4.160	-	Buhl and Hamilton 1991
Coho salmon (adult), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	17.5[d]	-	40.32[d]	-	Chapman 1975
Coho salmon (parr), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	2.7	-	<u>6.221</u>	6.221	Chapman 1975
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	-	6.016	-	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	-	8.048	-	Hamilton and Buhl 1990
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>26[d]	-	>57.26[d]	-	Chapman 1975, 1978
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	-	<u>3.964</u>	-	Chapman 1975, 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	-	<u>7.707</u>	-	Chapman 1975, 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>2.9	-	<u>>6.386</u>	-	Chapman 1975, 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	-	<u>2.853</u>	-	Chapman 1982
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21 (20-22)	1.1	-	<u>2.657</u>	4.305	Finlayson and Verrue 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	6	-	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	7	-	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	Cadmium chloride	-	6.0	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	43.5 (39-48)	2.3	-	2.650	-	Spehar and Carlson 1984a,b
Rainbow trout (juvenile), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	1.5	-	1.835	-	Buhl and Hamilton 1991
Rainbow trout (alevin), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>27[d]	-	>59.46[d]	-	Chapman 1975, 1978
Rainbow trout (swim-up), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.3	-	<u>2.863</u>	-	Chapman 1975, 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.0	-	<u>2.202</u>	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	4.1 >2.9	-	<u>9.029</u> <u>>6.386</u>	- -	Chapman 1975
Rainbow trout (2 mo), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	-	6.6	-	-	-	Hale 1977
Rainbow trout, *Oncorhynchus mykiss*	F, M	Cadmium sulfate	31	1.75	-	<u>2.845</u>	-	Davies 1976
Rainbow trout (8.8 g), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	44.4	3	-	<u>3.385</u>	-	Phipps and Holcombe 1985
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	9.2	<0.5	-	<u><2.795</u>	-	Cusimano et al. 1986
Rainbow trout (263 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.7	0.71 (pH=7.5 @ 8°C)	-	<u>1.166</u>	-	Stratus Consulting 1999
Rainbow trout (659 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	29.3	0.47 (pH=7.5 @ 8°C)	-	<u>0.8092</u>	-	Stratus Consulting 1999

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
FRESHWATER SPECIES								
Rainbow trout (1150 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	31.7	0.51 (pH=7.5 @ 8°C)	-	**0.8105**	-	Stratus Consulting 1999
Rainbow trout (1130 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.2	0.38 (pH=7.5 @ 12°C)	-	**0.6344**	-	Stratus Consulting 1999
Rainbow trout (299 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.0	1.29 (pH=6.5 @ 8°C)	-	**2.168**	-	Stratus Consulting 1999
Rainbow trout (289 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	89.3	2.85 (pH=7.5 @ 8°C)	-	**1.581**	2.108	Stratus Consulting 1999
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	43.5 (39-48)	1.4	-	**1.613**	1.613	Spehar and Carlson 1984a,b
Brook trout, *Salvelinus fontinalis*	F, M	Cadmium chloride	47.4	5,080[e]	-	5,363[e]	-	Holcombe et al. 1983
Brook trout, *Salvelinus fontinalis*	S, M	Cadmium sulfate	42	<1.5	-	**<1.791**	<1.791	Carroll et al. 1979
Bull trout (76.1 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.7	0.91 (pH=7.5 @ 8°C)	-	**1.494**	-	Stratus Consulting 1999
Bull trout (200 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	29.3	0.99 (pH= 7.5 @ 8°C)	-	**1.705**	-	Stratus Consulting 1999
Bull trout (221 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	31.7	1.00 (pH=7.5 @ 8°C)	-	**1.589**	-	Stratus Consulting 1999
Bull trout (218 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.2	0.90 (pH=7.5 @ 12°C)	-	**1.503**	-	Stratus Consulting 1999
Bull trout (84.2 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.0	2.89 (pH=6.5 @ 8°C)	-	**4.858**	-	Stratus Consulting 1999
Bull trout (72.7 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	89.3	6.06 (pH=7.5 @ 8°C)	-	**3.361**	2.152	Stratus Consulting 1999
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	-	5,940	-	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	20	2,130	-	5,407	-	McCarty et al. 1978

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	-	16,431	-	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M, T	Cadmium chloride	44.4	748	-	844.0	844.0	Phipps and Holcombe 1985
Common carp (yolk absorbed), *Cyprinus carpio*	R, U	Cadmium chloride	-	140	-	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,840	-	-	-	Ramesha et al. 1997
Common carp (advanced fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,910	-	-	-	Ramesha et al. 1997
Common carp (fingerling), *Cyprinus carpio*	R, U	Cadmium chloride	-	4,560	-	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	S, U	Cadmium nitrate	100	4,300	-	2,125	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U	Cadmium nitrate	100	17,100	-	8,452	4,238	Suresh et al. 1993a
Red shiner (0.8 - 2.0g) *Notropis lutrensis*	S, M, T	Cadmium sulfate	85.5	6,620	-	3,837	3,837	Carrier and Beitinger 1988a
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	1,050[d]	-	2,665[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	630[d]	-	1,599[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	72,600[d]	-	9,758[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	73,500[d]	-	9,879[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200[d]	-	2,722[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000[d]	-	2,917[d]	-	Pickering and Gast 1972

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400[d]	4,600[d]	1,556[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000[d]	1,400[d]	486.2[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500[d]	2,800[d]	1,094[d]	-	Pickering and Gast 1972
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	-	**26.97**	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	-	**12.20**	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	-	**24.85**	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	-	**47.19**	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	-	**57.72**	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	-	**33.02**	-	Spehar 1982
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060[d]	-	1,468[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900[d]	-	1,391[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100[d]	-	1,487[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5 (254-271)	7,160[d]	-	1,327[d]	-	Birge et al. 1983

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	43.5 (39-48)	1,280[d]	-	1,475[d]	-	Spehar and Carlson 1984a,b
Fathead minnow (14-30 d), *Pimephales promelas*	S, U	Cadmium chloride	120	>150[h]	-	>61.60[h]	-	Hall et al. 1986
Fathead minnow (0.8 - 2.0 g) *Pimephales promelas*	S, M, T	Cadmium sulfate	85.5	3,580[d]	-	2,075[d]	-	Carrier and Beitinger 1988a
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	-	**174.5**	-	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	-	**149.5**	-	Rifici et al. 1996
Fathead minnow (<24 hr), *Pimephales promelas*	S, M, T	Cadmium nitrate	290 (280-300)	73 (pH=6-6.5) 60 (pH=7-7.5) 65 (pH=8-8.8)	- - -	**12.22** **10.05** **10.88**	- - -	Schubauer-Berigan et al. 1993
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,420[d]	2,590	1,192[d]	-	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,510[d]	2,430	1,223[d]	-	Sherman et al. 1987
Fathead minnow (0.6 g), *Pimephales promelas*	F, M, T	Cadmium chloride	44.4	1,500[d]	-	1,693[d]	-	Phipps and Holcombe 1985
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	13.2	-	**15.03**	29.21	Spehar and Fiandt 1986
Colorado squawfish (larva), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	78	-	**19.15**	-	Buhl 1997
Colorado squawfish (juvenile), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	108	-	**26.52**	22.54	Buhl 1997

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Northern pike minnow (juvenile), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25 (20-30)	1,092	-	**2,209**	-	Andros and Garton 1980
Northern pike minnow (juvenile), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25 (20-30)	1,104	-	**2,234**	2,221	Andros and Garton 1980
Bonytail (larva), *Gila elegans*	S, U	Cadmium chloride	199	148	-	**36.34**	-	Buhl 1997
Bonytail (juvenile), *Gila elegans*	S, U	Cadmium chloride	199	168	-	**41.25**	38.72	Buhl 1997
White sucker, *Catostomus commersoni*	F, M	Cadmium chloride	18	1,110	-	**3,136**	3,136	Duncan and Klaverkamp 1983
Razorback sucker (larva), *Xyrauchen texanus*	S, U	Cadmium chloride	199	139	-	**34.13**	-	Buhl 1997
Razorback sucker (juvenile), *Xyrauchen texanus*	S, U	Cadmium chloride	199	160	-	**39.29**	36.62	Buhl 1997
Channel catfish (7.4 g), *Ictalurus punctatus*	F, M, T	Cadmium chloride	44.4	4,480	-	**5,055**	5,055	Phipps and Holcombe 1985
Flagfish, *Jordanella floridae*	F, M	Cadmium chloride	44	2,500	-	**2,847**	2,847	Spehar 1976a,b
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	900	-	**4,157**	-	Giesy et al. 1977
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	2,200	-	**10,161**	6,499	Giesy et al. 1977
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	-	**3,224**	-	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	105	3,800	-	**1,787**	-	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	209.2	11,100	-	**2,591**	2,462	Canton and Slooff 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Threespine stickleback, *Gasterosteus aculeatus*	S, U	Cadmium chloride	115	6,500	-	2,787	-	Pascoe and Cram 1977
Threespine stickleback, *Gasterosteus aculeatus*	R, M	Cadmium chloride	107 (103-111)	23,000	-	10,613	5,439	Pascoe and Mattey 1977
Striped bass (larva), *Morone saxatilis*	S, U	Cadmium chloride	34.5	1	-	1.458[e]	-	Hughes 1973
Striped bass (fingerling), *Morone saxatilis*	S, U	Cadmium chloride	34.5	2	-	2.917[e]	-	Hughes 1973
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	-	5.019	-	Palawski et al. 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	-	1.704	2.925	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	-	7,208	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	-	8,871	-	Pickering and Henderson 1966
Green sunfish (juvenile), *Lepomis cyanellus*	S, M, T	Cadmium sulfate	85.5	11,520	-	6,677	-	Carrier and Beitinger 1988b
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	-	2,965	2,965	Jude 1973
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	-	4,924	-	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	-	6,498	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	-	6,498	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	-	4,978	-	Eaton 1980

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Bluegill (1.0 g), *Lepomis macrochirus*	F, M, T	Cadmium chloride	44.4	6,470	-	**7,300**	6,028	Phipps and Holcombe 1985
Tilapia *Oreochromis mossambica*	R, U	Cadmium chloride	28.4	6,000[d]	-	**10,663**	10,663	Gaikwad 1989
African clawed frog, *Xenopus laevis*	R, U	Cadmium chloride	116 (112-120)	3,597	-	**1,529**	1,529	Sunderman et al. 1991
Salamander (3 mo larva), *Ambystoma gracile*	F, M, T	Cadmium chloride	45	468.4	-	**521.4**	521.4	Nebeker et al. 1995

a S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.
b Results are expressed as cadmium, not as the chemical.
c Freshwater Species Mean Acute Values are calculated at a hardness of 50 mg/L using the pooled slope. SMAVs calculated using Lotus spreadsheet, values presented may be different than those calculated with a hand held calculator due to rounding.
Note: Each SMAV was calculated from the associated underlined number(s) in the preceding column.
d Not used in calculations because data are available for a more sensitive life stage.
e Not used in calculations (see text).
f Not used in calculations because data are available for a more sensitive test condition.
g Average of values calculated using log-probit and Spearman-Karber statistical methods.
h "Greater than" and "less than" values were not used in calculations.

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)	Reference
SALTWATER SPECIES							
Polychaete worm (adult), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	<u>12,000</u>	-	-	Reish et al. 1976
Polychaete worm (juvenile), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	<u>12,500</u>	-	-	Reish et al. 1976
Polychaete worm, *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	<u>14,100</u>	-	12,836	Reish and LeMay 1991
Polychaete worm, *Nereis grubei*	S, U	Cadmium chloride	-	<u>4,700</u>	-	4,700	Reish and LeMay 1991
Sand worm, *Nereis virens*	S, U	Cadmium chloride	-	<u>11,000</u>	-	-	Eisler 1971
Sand worm, *Nereis virens*	S, U	Cadmium chloride	-	<u>9,300</u>	-	10,114	Eisler and Hennekey 1977
Polychaete worm (adult), *Capitella capitata*	S, U	Cadmium chloride	-	7,500[c]	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	S, U	Cadmium chloride	-	2,800[c]	-	-	Reish and LeMay 1991
Polychaete worm (larva), *Capitella capitata*	S, U	Cadmium chloride	-	<u>200</u>	-	200	Reish et al. 1976
Polychaete worm, *Pectinaria californiensis*	S, U	Cadmium chloride	-	<u>2,600</u>	-	2,600	Reish and LeMay 1991
Oligochaete worm, *Limnodriloides verrucosus*	R, U	Cadmium sulfate	-	<u>10,000</u>	-	10,000	Chapman et al. 1982
Oligochaete worm, *Monopylephorus cuticulatus*	R, U	Cadmium sulfate	-	<u>135,000</u>	-	135,000	Chapman et al. 1982
Oligochaete worm, *Tubificoides gabriellae*	R, U	Cadmium sulfate	-	<u>24,000</u>	-	24,000	Chapman et al. 1982
Oyster drill, *Urosalpinx cinerea*	S, U	Cadmium chloride	-	<u>6,600</u>	-	6,600	Eisler 1971

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	10,500	-	-	Eisler 1971
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	35,000	-	19,170	Eisler and Hennekey 1977
Blue mussel, *Mytilus edulis*	S, U	Cadmium chloride	-	25,000[e]	-	-	Eisler 1971
Blue mussel, *Mytilus edulis*	S, M	Cadmium chloride	-	1,620[e]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	3,600[e]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	4,300[e]	-	-	Ahsanullah 1976
Blue mussel (embryo), *Mytilus edulis*	S, U	Cadmium chloride	-	1,200	-	-	Martin et al. 1981
Blue Mussel (juvenile), *Mytilus edulis*	R, U	Cadmium chloride	2.5	960	-	1,073	Nelson et al. 1988
Bay scallop (juvenile), *Argopecten irradians*	S, U	Cadmium chloride	-	1,480	-	1,480	Nelson et al. 1976
Pacific oyster (embryo), *Crassostrea gigas*	S, U	Cadmium chloride	-	611	-	-	Martin et al. 1981
Pacific oyster (larva), *Crassostrea gigas*	S, U	Cadmium chloride	-	85	-	227.9	Watling 1982
Eastern oyster (larva), *Crassostrea virginica*	S, U	Cadmium chloride	-	3,800	-	3,800	Calabrese et al. 1973
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,200	-	-	Eisler 1971
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,500	-	-	Eisler and Hennekey 1977
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	850	-	1,672	Eisler 1977
Squid (larva), *Loligo opalescens*	S, M, T	Cadmium chloride	30	>10,200	-	>10,200	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	S, U	Cadmium chloride	-	1,708	-	1,708	Gentile 1982

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Copepod, *Eurytemora affinis*	S, U	Cadmium chloride	-	1,080[e]	-	-	Gentile 1982
Copepod (naupilus), *Eurytemora affinis*	S, U	Cadmium chloride	-	147.7	-	147.7	Sullivan et al. 1983
Copepod, *Acartia clausi*	S, U	Cadmium chloride	-	144	-	144	Gentile 1982
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	90	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	122	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	220	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	337	-	-	Sosnowski and Gentile 1978
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	15	93 (18°C)	-	-	Toudal and Riisgard 1987
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20	151 (13°C)	-	-	Toudal and Riisgard 1987
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20	29 (21°C)	-	118.7	Toudal and Riisgard 1987
Copepod, *Amphiascus tenuiremis*	S, M, T	Cadmium nitrate	30.7	224	-	224	Green et al. 1993
Copepod, *Nitocra spinipes*	S, U	Cadmium chloride	-	1,800	-	-	Bengtsson 1978
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	3	430	-	-	Bengtsson and Bergstrom 1987
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	7	660	-	-	Bengtsson and Bergstrom 1987
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	15	780	-	794.5	Bengtsson and Bergstrom 1987

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	6	14.7	2.8	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	14	38.0	3.6	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	22	70.4	4.1	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	30	77.3	2.9	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	38	90.3	2.3	-	De Lisle and Roberts 1988
Mysid (<24 hr), *Americamysis bahia*	S, M, T	-	10	30.9 (20°C) <11.1 (30°C)	- -	- -	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M, T	-	30	82.0 (20°C) 32.8 (25°C) <11.1 (30°C)	- - -	- - -	Voyer and Modica 1990
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	10-17	<u>15.5</u>	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	30	<u>110</u>	-	41.29	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Mysidopsis bigelowi*	F, M	Cadmium chloride	30	<u>110</u>	-	110	Gentile et al. 1982
Iosopd, *Jaeropsis* sp.	S, U	Cadmium chloride	35	<u>410.0</u>	-	410.0	Hong and Reish 1987
Isopod, *Limnoria tripunctata*	S, U	Cadmium chloride	35	<u>7,120</u>	-	7,120	Hong and Reish 1987
Amphipod (adult), *Ampelisca abdita*	F, M	Cadmium chloride	-	<u>2,900</u>	-	2,900	Scott et al. Manuscript
Amphipod (adult), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	13,000[e]	-	-	Wright and Frain 1981
Amphipod (young), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	<u>3,500</u>	-	3,500	Wright and Frain 1981

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Amphipod, *Chelura terebrans*	S, U	Cadmium chloride	35	630	-	630	Hong and Reish 1987
Amphipod, *Corophium insidiosum*	S, U	Cadmium chloride	35	1,270	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Corophium insidiosum*	S, U	Cadmium chloride	-	680	-	929.3	Reish 1993
Amphipod (juvenile), *Diporeia* spp.	S, M, T	Cadmium chloride	20 (4°C)	49,400[d]	-	-	Gossiaux et al. 1992
			20 (10°C)	17,500[d]	-	-	
			20 (15°C)	6,700	-	6,700	
Amphipod, *Elasmopus bampo*	S, U	Cadmium chloride	35	570	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Elasmopus bampo*	S, U	Cadmium chloride	-	900	-	716.2	Reish 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M, T	Cadmium chloride	30	41,900 (held 11 d before testing)	-	-	Meador 1993
				36,100 (held 17 d before testing)	-	-	
				14,500 (held 121 d before testing)	-	27,992	
Amphipod, *Grandidierella japonica*	S, U	Cadmium chloride	35	1,170	-	1,170	Hong and Reish 1987
Amphipod (500 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	360	-	-	McGee et al. 1998
Amphipod (700 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	650	-	-	McGee et al. 1998
Amphipod (1,000 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	880	-	590.5	McGee et al. 1998
Pink shrimp (subadult), *Penaeus duorarum*	F, M	Cadmium chloride	-	3,500[e]	-	-	Nimmo et al. 1977b
Pink shrimp (2nd post larva), *Penaeus duorarum*	S, U	cadmium chloride	25	310.5	-	310.5	Cripe 1994

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	1,830 (Big Sheepshead Creek)	-	-	Khan et al. 1988
Grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	3,280 (Pine Creek)	-	-	Khan et al. 1988
Grass shrimp (juvenile). *Palaemonetes pugio*	S, M, T	Cadmium chloride	10	1,300	-	1,983	Burton and Fisher 1990
Grass shrimp, *Palaemonetes vulgaris*	S, U	Cadmium chloride	-	420	-	-	Eisler 1971
Grass shrimp, *Palaemonetes vulgaris*	F, M	Cadmium chloride	-	760	-	760	Nimmo et al. 1977b
Sand shrimp, *Crangon septemspinosa*	S, U	Cadmium chloride	-	320	-	320	Eisler 1971
American Lobster (larva), *Homarus americanus*	S, U	Cadmium chloride	-	78	-	78	Johnson and Gentile 1979
Hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	320	-	-	Eisler 1971
Hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	1,300	-	645.0	Eisler and Hennekey 1977
Rock crab (zoea), *Cancer irroratus*	F, M	Cadmium chloride	-	250	-	250	Johns and Miller 1982
Dungeness crab (zoea), *Cancer magister*	S, U	Cadmium chloride	-	247	-	-	Martin et al. 1981
Dungeness crab (zoea), *Cancer magister*	S, M, T	Cadmium chloride	30	200	-	222.3	Dinnel et al. 1989
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	35	11,600	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	15	4,700	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	1	320	-	2,594	Frank and Robertson 1979
Green crab, *Carcinus maenas*	S, U	Cadmium chloride	-	4,100	-	4,100	Eisler 1971
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20	46,600	-	-	O'Hara 1973a

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30	37,000	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10	32,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	23,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	10,400	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	6,800	-	21,238	O'Hara 1973a
Starfish, *Asterias forbesi*	S, U	Cadmium chloride	-	820	-	-	Eisler 1971
Starfish, *Asterias forbesi*	S, U	Cadmium chloride	-	7,100	-	2,413	Eisler and Hennekey 1977
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	S, M, T	Cadmium chloride	30	1,800	-	1,800	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M, T	Cadmium chloride	30	500	-	500	Dinnel et al. 1989
Sand dollar (embryo), *Dendraster excentricus*	S, M, T	Cadmium chloride	30	7,400	-	7,400	Dinnel et al. 1989
Coho salmon (smolt), *Oncorhynchus kisutch*	F, M, T	Cadmium chloride	28.3	1,500	-	1,500	Dinnel et al. 1989
Sheepshead minnow, *Cyprinodon variegatus*	S, U	Cadmium chloride	-	50,000	-	50,000	Eisler 1971
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	49,000	-	-	Eisler 1971
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	114,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	92,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	78,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000	-	-	Voyer 1975

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	63,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	31,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	30,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	29,000	-	-	Voyer 1975
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	22,000	-	-	Eisler and Hennekey 1977
Mummichog (12-20 mm), *Fundulus heteroclitus*	F, M, T	Cadmium sulfate	14	18,200	-	18,200	Lin and Dunson 1993
Striped killifish (adult), *Fundulus majalis*	S, U	Cadmium chloride	-	21,000	-	21,000	Eisler 1971
Rivulus (30 d juvenile) *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	18,800[e]	-	-	Park et al. 1994
Rivulus (120 d adult), *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	32,200[e]	-	-	Park et al. 1994
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M, T	Cadmium sulfate	14	23,700[e]	-	-	Lin and Dunson 1993
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M, T	Cadmium sulfate	14	18,500[e]	-	-	Lin and Dunson 1993
Rivulus (7 d larva), *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	800	-	800	Park et al. 1994
Atlantic silverside (adult), *Menidia menidia*	S, U	Cadmium chloride	-	2,032[e]	-	-	Cardin 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	-	28,532[e]	-	-	Cardin 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	-	13,652[e]	-	-	Cardin 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Cadmium chloride	-	1,054	-	-	Cardin 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Cadmium chloride	-	577	-	779.8	Cardin 1982

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	1	75.0	-	75.0	Palawski et al. 1985
Cabezon (larva), *Scorpaenichthys marmoratus*	S, M, T	Cadmium chloride	27	>200	-	>200.0	Dinnel et al. 1989
Shiner perch (87 mm adult), *Cymatogaster aggregata*	F, M, T	Cadmium chloride	30.1	11,000	-	11,000	Dinnel et al. 1989
Striped mullet (50 mm juvenile), *Mugil cephalus*	S, U	Cadmium chloride	37.3	28,000[c]	-	-	Hilmy et al. 1985
Striped mullet (10 mm fry), *Mugil cephalus*	S, U	Cadmium chloride	37.3	7,079	-	7,079	Hilmy et al. 1985
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	602[e]	-	-	Cardin 1982
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	14,297	-	14,297	Cardin 1982

a S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.
b Results are expressed as cadmium, not as the chemical.
c Not used in calculations because data are available for a more sensitive life stage.
d Not used in calculations because data are available for a more sensitive test condition.
e Not used in calculations because this lower value was obtained in artificial sea water.

Table 1c. Results of Covariance Analysis of Freshwater Acute Toxicity Versus Hardness

Species	n	Slope	R^2 Value	95% Confidence Limits	Degrees of Freedom
Limnodrilus hoffmeisteri	2	0.7888	---	cannot calculate	0
Tubifex tubifex	3	0.6238	0.929	-1.5619, 2.8095	1
Vilosa vibex	2	0.9286	---	cannot calculate	0
Daphnia magna (all data)	28	0.1086	0.002	-0.7975, 1.0147	26
Daphnia magna (Chapman et al. Manuscript)	5	1.1824*	0.915	0.5195, 1.8454	3
Daphnia pulex	8	1.0633*	0.792	0.5191, 1.6074	6
Chinook salmon	6	1.2576*	0.947	0.8461, 1.6691	4
Goldfish	4	1.4608	0.570	-2.3973, 5.3190	2
Fathead minnow (all data)	28	2.0305*	0.450	1.1247, 2.9362	26
Fathead minnow (adults only)	18	1.2209*	0.699	0.7962, 1.6456	16
Guppy	3	0.8752	0.949	-1.6995, 3.4499	1
Striped bass	4	0.8089	0.722	-0.7182, 2.3359	2
Green sunfish	4	0.8986	0.880	-0.1127, 1.9098	2
Bluegill	5	0.9531*	0.974	0.6667, 1.2395	3
All of above using all data for *D. magna*	97	1.1741*@	0.778	0.8346, 1.5136	85
All of above except using only data from Chapman et al. (Manuscript) for *D. magna* and only adult fathead minnow data	64	1.0166*#	0.967	0.9745, 1.0588	52

* Slope is significantly different than 0 ($p<0.05$).
@ Individual slopes not significantly different ($p=0.27$).
# Individual slopes not significantly different ($p=0.69$).

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Tubificid worm, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	Chapman et al. 1982a
Tubificid worm (30-40 mm), *Limnodrilus hoffmeisteri*	F, M, T	-	152	2,400	Williams et al. 1985
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	3,200	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	1,700	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	Chapman et al. 1982a
Mussel, *Vilosa vibex*	S, M, T	-	40	30	Keller Unpublished
Mussel, *Vilosa vibex*	S, M, T	-	186	125	Keller Unpublished
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	105	30	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	209.2	30	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	Hall et al. 1986

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total μg/L)[c]	Reference
		FRESHWATER SPECIES			
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	3.6 (genotype A)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-1)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-2)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	4.5 (genotype B)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	27.1 (genotype E)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	115.9 (genotype S-1)	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	24.5 (Clone F)	Stuhlbacher et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	129.4 (Clone S-1)	Stuhlbacher et al. 1992
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	Crisinel et al. 1994
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170 (160-180)	9.5	Guilhermino et al. 1996
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	112 (clone S-1)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	106 (clone S-1)	Barata et al. 1998

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	233 (clone S-1)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	30.1 (clone A)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	23.4 (clone A)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	23.6 (clone A)	Barata et al. 1998
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	51	9.9	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	104	33	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	105	34	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	197	63	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	209	49	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	F, M, T	Cadmium Chloride	130	58	Attar and Maly 1982
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	Bertram and Hart 1979
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	Hall et al. 1986

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	53.5	70.1	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	66	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	(85) (80-90)	99	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	70	Roux et al. 1993
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	Hamilton and Buhl 1990
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	Chapman 1975, 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	Chapman 1975, 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	Chapman 1982
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21 (20-22)	1.1	Finlayson and Verrue 1982
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium	20	2,130	McCarty et al. 1978

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total $\mu g/L$)[c]	Reference
			FRESHWATER SPECIES		
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M, T	Cadmium chloride	44.4	748	Phipps and Holcombe 1985
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	1,050[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	630[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	72,600[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	73,500[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500[d]	Pickering and Gast 1972
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060[d]	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900[d]	Birge et al. 1983

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total μg/L)[c]	Reference
			FRESHWATER SPECIES		
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100[d]	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5 254-271	7,160[d]	Birge et al. 1983
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	43.5 39-48	1,280[d]	Spehar and Carlson 1984a,b
Fathead minnow (0.8 - 2.0 g), *Pimephales promelas*	S, M, T	Cadmium sulfate	85.5	3,580[d]	Carrier and Beitinger 1988a
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,420[d]	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,510[d]	Sherman et al. 1987
Fathead minnow (0.6 g), *Pimephales promelas*	F, M, T	Cadmium chloride	44.4	1,500[d]	Phipps and Holcombe 1985
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	Spehar 1982

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	Rifici et al. 1996
Fathead minnow (<24 hr), *Pimephales promelas*	S, M, T	Cadmium nitrate	290 280-300	60 (pH=7-7.5)	Schubauer-Berigan et al. 1993
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	13.2	Spehar and Fiandt 1986
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	105	3,800	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	209.2	11,100	Canton and Slooff 1982
Striped bass (larva), *Morone saxatilis*	S, U	Cadmium chloride	34.5	1	Hughes 1973
Striped bass (fingerling), *Morone saxatilis*	S, U	Cadmium chloride	34.5	2	Hughes 1973
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	Palawski et al. 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	Pickering and Henderson 1966

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	Pickering and Henderson 1966
Green sunfish (juvenile), *Lepomis cyanellus*	S, M, T	Cadmium sulfate	85.5	11,520	Carrier and Beitinger 1988b
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	Jude 1973
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	Eaton 1980
Bluegill (1.0 g), *Lepomis macrochirus*	F, M, T	Cadmium chloride	44.4	6,470	Phipps and Holcombe 1985

a Only those species listed in Table 1a that satisfied EPA Guideline requirements for inclusion were used to determine acute hardness slope. In addition, less than or greater than values were not used, nor were daphnid tests initiated with >24 hr old neonates.

b S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.

c Results are expressed as cadmium, not as the chemical.

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[b]	Chronic Limits Diss. (µg/L)[b]	Chronic Value Total (µg/L)[b]	Chronic Value Diss. (µg/L)[b]	Chronic Value Adj. to TH=50 (Total µg/L)	Species Mean Chronic Value at TH=50 (Total µg/L)[c]	Reference
FRESHWATER SPECIES										
Oligochaete, *Aeolosoma headleyi*	LC	-	65	-	-	25.19	-	20.74	20.74	Niederlehner 1984
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	4.41-7.63	-	5.801	-	6.241	-	Holcombe et al. 1984
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	2.50-4.79	-	3.460	-	3.723	4.820	Holcombe et al. 1984
Cladoceran, *Ceriodaphnia dubia*	LC	-	20	10-19	-	13.78	-	27.17	27.17	Jop et al. 1995
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	53	0.08-0.29	-	0.1523	-	0.1459	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	cadmium chloride	103	0.16-0.28	-	0.2117	-	0.1239	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	209	0.21-0.91	-	0.4371	-	0.1515	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	150	5.0-10.0	-	7.07	-	3.133	-	Bodar et al. 1988b
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	130	<1.86-1.86	-	<1.86	-	<0.9163	<0.3794	Borgmann et al. 1989
Cladoceran, *Daphnia pulex*	LC	-	65	-	-	7.49	-	6.167	6.167	Niederlehner 1984
Amphipod, *Hyalella azteca*	LC	Cadmium chloride	280	0.51-1.9	-	0.9844	-	0.2747	0.2747	Ingersoll and Kemble Unpublished
Midge, *Chironomus tentans*	LC	Cadmium chloride	280	5.8-17.4	-	10.05	-	2.804	2.804	Ingersoll and Kemble Unpublished

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[b]	Chronic Limits Diss. (µg/L)[b]	Chronic Value Total (µg/L)[b]	Chronic Value Diss. (µg/L)[b]	Chronic Value Total at TH=50 (Total µg/L)	Species Mean Chronic Value at TH=50 (Total µg/L)[c]	Reference
					FRESHWATER SPECIES					
Coho salmon (Lake Supr.), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	1.3-3.4	-	2.102	-	**2.311**	-	Eaton et al. 1978
Coho salmon (West Coast), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	4.1-12.5	-	7.159	-	**7.870**	4.265	Eaton et al. 1978
Chinook salmon, *Oncorhynchus tshawytscha*	ELS	Cadmium chloride	25	1.3-1.88	-	1.563	-	**2.612**	2.612	Chapman 1975
Rainbow trout (270 d), *Oncorhynchus mykiss*	LC	Cadmium sulfate	250	3.39-5.48	-	4.310	-	**1.308**	1.308	Brown et al. 1994
Atlantic salmon, *Salmo salar*	ELS	Cadmium chloride	23.5 (19-28)	90-270 (5°C)	-	155.9[e]	-	272.8[d]	-	Rombough and Garside 1982
				2.5-8.2 (9.6°C)	-	4.528	-	**7.922**	7.922	
Brown trout, *Salmo trutta*	ELS	Cadmium chloride	44	3.8-11.7	-	6.668	-	7.330	-	Eaton et al. 1978
Brown trout, *Salmo trutta*	LC	Cadmium sulfate	250	9.34-29.1	-	16.49	-	**5.004**	5.004	Brown et al. 1994
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	37	1-3	-	1.732	-	2.165	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	44	1.1-3.8	-	2.045	-	2.248	-	Eaton et al. 1978
Brook trout, *Salvelinus fontinalis*	LC	Cadmium chloride	44	1.7-3.4	-	2.404	-	**2.643**	2.643	Benoit et al. 1976
Lake trout, *Salvelinus namaycush*	ELS	Cadmium chloride	44	4.4-12.3	-	7.357	-	**8.088**	8.088	Eaton et al. 1978
Northern pike, *Esox lucius*	ELS	Cadmium chloride	44	4.2-12.9	-	7.361	-	**8.092**	8.092	Eaton et al. 1978

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[b]	Chronic Limits Diss. (µg/L)[b]	Chronic Value Total (µg/L)[b]	Chronic Value Diss. (µg/L)[b]	Chronic Value Total at TH=50 (Total µg/L)	Species Mean Chronic Value at TH=50 (Total µg/L)[c]	Reference
					FRESHWATER SPECIES					
Fathead minnow, *Pimephales promelas*	ELS	Cadmium nitrate	44	-	-	10.0	-	10.99	-	Spehar and Fiandt 1986
Fathead minnow, *Pimephales promelas*	LC	Cadmium sulfate	201	37-57	-	45.92	-	16.38	16.38	Pickering and Gast 1972
White sucker, *Catostomus commersoni*	ELS	Cadmium chloride	44	4.2-12.0	-	7.099	-	7.804	7.804	Eaton et al. 1978
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	44	4.1-8.1	-	5.763	-	6.336	-	Spehar 1976a
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	47.5 (44-51)	3.0-6.5	-	4.416	-	4.587	-	Carlson et al. 1982
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	47.5 (44-51)	3.4-7.3	-	4.982	-	5.175	5.318	Carlson et al. 1982
Bluegill, *Lepomis macrochirus*	LC	Cadmium sulfate	207	31-80	-	49.80	-	17.38	17.38	Eaton 1974
Smallmouth bass, *Micropterus dolomieui*	ELS	Cadmium chloride	44	4.3-12.7	-	7.390	-	8.124	8.124	Eaton et al. 1978
Blue tilapia, *Oreochromis aurea*	LC	Cadmium nitrate	145	>52	-	>52	-	>23.63	>23.63	Papoutsoglou and Abel 1988

a ELS = early life stage, LC = life cycle or partial life cycle.
b Results are expressed as cadmium, not as the chemical.
c Each SMCV was calculated from the associated underlined number(s) in the preceding column.
d Not used in calculations (see text).

Table 2b. Chronic Toxicity of Cadmium to Saltwater Animals

Species	Test[a]	Chemical	Salinity (g/kg)	Chronic Limits Total (µg/L)[b]	Chronic Limits Dissolved (µg/L)	Chronic Value Total (µg/L)	Chronic Value Dissolved (µg/L)	Species Mean Chronic Value (Total µg/L)[c]	Reference
					SALTWATER SPECIES				
Mysid, *Americamysis bahia*	LC	Cadmium chloride	15-23	6.4-10.6	-	**8.237**	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	LC	Cadmium chloride	30	5.1-10	-	**7.141**	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Americamysis bahia*	LC	Cadmium chloride	30	<4-4	-	≤4	-	6.173	Carr et al. 1985
Mysid, *Mysidopsis bigelowi*	LC	Cadmium chloride	-	5.1-10	-	**7.141**	-	7.141	Gentile et al. 1982

a ELS = early life stage, LC = life cycle or partial life cycle.
b Results are expressed as cadmium, not as the chemical.
c Each SMCV was calculated from the associated underlined number(s) in the preceding column.

Table 2c. Results of Covariance Analysis of Freshwater Chronic Toxicity Versus Hardness

Species	n	Slope	R^2 Value	95% Confidence Limits	Degrees of Freedom
Daphnia magna - All	4	1.5792	0.284	-6.0524, 9.2108	2
Daphnia magna (only Chapman et al. Manuscript)	3	0.7712	0.962	-1.1663, 2.7087	1
Brown trout	2	0.5212	---	Cannot be calculated	0
Fathead minnow	2	1.0034	---	Cannot be calculated	0
All species	8	0.9685@	0.779	-0.9716, 2.9087	5
All species (Chapman only)	7	0.7409*#	0.994	0.3359, 1.1459	4

* Slope is significantly different from 0 ($p<0.05$).
@ Individual slopes not significant different ($p=0.90$).
# Individual slopes not significant different ($p=0.35$).

Table 2d. List of Studies Used to Estimate Chronic Cadmium Hardness Slope

Species[a]	Test[b]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[c]	Chronic Value Total (µg/L)[c]	Reference
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	53	0.08-0.29	0.1523	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	103	0.16-0.28	0.2117	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	209	0.21-0.91	0.4371	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	150	5.0-10.0	7.07	Bodar et al. 1988b
Brown trout, *Salmo trutta*	ELS	Cadmium chloride	44	3.8-11.7	6.668	Eaton et al. 1978
Brown trout, *Salmo trutta*	LC	Cadmium sulfate	250	9.34-29.1	16.49	Brown et al. 1994
Fathead minnow, *Pimephales promelas*	LC	Cadmium sulfate	201	37-57	45.92	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	ELS	Cadmium nitrate	44	-	10.0	Spehar and Fiandt 1986

a Only those species listed in Table 2a that satisfied EPA Guideline requirements for inclusion were used to determine chronic hardness slope. In addition, less than or greater than values were not used.
b ELS = early life stage, LC = life cycle or partial life cycle.
c Results are expressed as cadmium, not as the chemical.

Table 2e. Cadmium Acute-Chronic Ratios

Species	Reference	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species Mean Acute-Chronic Ratio
Freshwater Species						
Snail, *Aplexa hypnorum*	Holcombe et al. 1984	45.3	93	5.801	16.03	-
Snail, *Aplexa hypnorum*	Holcombe et al. 1984	45.3	93	3.460	26.88	20.76
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	51	9.9	0.1523	65.00	-
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	104	33	0.2117	155.9	-
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	209	49	0.4371	112.1	104.3
Chinook salmon, *Oncorhynchus tshawytscha*	Chapman 1975, 1982	25	1.41	1.563	0.9021	0.9021
Fathead minnow, *Pimephales promelas*	Pickering and Gast 1972	201	5,995[a]	45.92	130.6	-
Fathead minnow, *Pimephales promelas*	Spehar and Fiandt 1986	44	13.2	10.0	1.320	13.13
Flagfish, *Jordanella floridae*	Spehar 1976a	44	2,500	5.763	433.8	433.8
Bluegill, *Lepomis macrochirus*	Eaton 1974	207	21,100	49.80	423.7	423.7
Saltwater Species						
Mysid, *Americamysis bahia*	Nimmo et al. 1977a	-	15.5	8.237	1.882	-
Mysid, *Americamysis bahia*	Gentile et al. 1982	-	110	7.141	15.40	5.384
Mysid, *Mysidopsis bigelowi*	Gentile et al. 1982	-	110	7.141	15.40	15.40

[a] Geometric mean of five values in Table 1 from Pickering and Gast (1972).

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

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
55	96,880	Midge, *Chironomus riparius*	96,880	-
54	14,067	Planarian, *Dendrocoelum lacteum*	14,067	-
53	>11,683	Crayfish, *Orconectes virilis*	11,859	-
		Crayfish, *Orconectes immunis*	>11,509	-
52	10,663	Tilapia, *Oreochromis mossambica*	10,663	-
51	6,499	Mosquitofish, *Gambusia affinis*	6,499	-
50	6,169	Tubificid worm, *Rhyacodrilus montana*	6,169	-
49	5,439	Threespine stickleback, *Gasterosteus aculeatus*	5,439	-
48	5,386	Tubificid worm, *Stylodrilus heringianus*	5,386	-
47	5,055	Channel catfish, *Ictalurus punctatus*	5,055	-
46	4,238	Common carp, *Cyprinus carpio*	4,238	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
45	4,228	Green sunfish, *Lepomis cyanellus*	2,965	-
		Bluegill, *Lepomis macrochirus*	6,028	423.7
44	3,886	Tubificid worm, *Spirosperma ferox*	3,427	-
		Tubificid worm, *Spirosperma nikolskyi*	4,406	-
43	3,837	Red shiner, *Notropis lutrenis*	3,837	-
42	3,721	Tubificid worm, *Varichaeta pacifica*	3,721	-
41	3,136	White sucker, *Catostomus commersoni*	3,136	-
40	3,133	Tubificid worm, *Quistradilus multisetosus*	3,133	-
39	2,847	Flagfish, *Jordanella floridae*	2,847	433.8
38	2,462	Guppy, *Poecilia reticulata*	2,462	-
37	2,350	Tubificid worm, *Branchiura sowerbyi*	2,350	-
36	2,278	Mayfly, *Ephemerella grandis*	2,278	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
35	1,748	Crayfish, *Procambarus clarkii*	1,748	-
34	1,700	Amphipod, *Crangonyx pseudogracilis*	1,700	-
33	1,529	African clawed frog, *Xenopus laevis*	1,529	-
32	1,361	Tubificid worm, *Tubifex tubifex*	1,361	-
31	844.0	Goldfish, *Carassius auratus*	844.0	-
30	775.0	Tubificid worm, *Limnodrilus hoffmeisteri*	775.0	-
29	521.4	Salamander, *Ambystoma gracile*	521.4	-
28	472.1	Isopod, *Asellus bicrenata*	472.1	-
27	259.7	Bryozoan, *Plumatella emarginata*	259.7	-
26	247.2	Cladoceran, *Alona affinis*	247.2	-
25	223.2	Copepod, *Cyclops varicans*	223.2	-
24	192.5	Leech, *Glossiponia complanta*	192.5	-

Table 3a. **Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)**

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
23	166.8	Bryozoan, *Pectinatella magnifica*	166.8	-
22	130.6	Worm, *Lumbriculus variegatus*	130.6	-
21	103.9	Snail, *Aplexa hypnorum*	103.9	20.76[c]
20	100.2	Snail, *Physa gyrina*	100.2	-
19	78.69	Amphipod, *Gammarus pseudolimnaeus*	78.69	-
18	48.44	Isopod, *Lirceus alabamae*	48.44	-
17	43.09	Cladoceran, *Moina macrocopa*	43.09	-
16	42.92	Mussel, *Utterbackia imbecilis*	42.92	-
15	38.72	Bonytail, *Gila elegans*	38.72	-
14	36.62	Razorback sucker, *Xyrauchen texanus*	36.62	-
13	35.90	Cladoceran, *Ceriodaphnia dubia*	31.37	-
		Cladoceran, *Ceriodaphnia reticulata*	41.07	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
12	35.74	Bryozoan, *Lophopodella carteri*	35.74	-
11	35.18	Mussel, *Vilosa vibex*	35.18	-
10	33.80	Mussel, *Actinonaia pectorosa*	33.80	-
9	33.76	Mussel, *Lampsilis straminea claibornensis*	47.68	-
		Mussel, *Lampsilis teres*	23.90	-
8	30.21	Cladoceran, *Simocephalus serrulatus*	30.21	-
7	29.21	Fathead minnow, *Pimephales promelas*	29.21	13.13[c]
6	24.93	Cladoceran, *Daphnia magna*	13.41	104.3[d]
		Cladoceran, *Daphnia pulex*	46.36	-
5	22.54	Colorado squawfish, *Ptychocheilus lucius*	22.54	-
		Northern pike minnow *Ptychocheilus oregonensis*	2,221[e]	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
4	3.836	Coho salmon, *Oncorhynchus kisutch*	6.221	-
		Chinook salmon, *Oncorhynchus tshawytscha*	4.305	0.9021
		Rainbow trout, *Oncorhynchus mykiss*	2.108	-
3	2.925	Striped bass, *Morone saxatilis*	2.925	-
2	<1.963	Brook trout, *Salvelinus fontinalis*	<1.791	-
		Bull trout, *Salvelinus confluentus*	2.152	-
1	1.613	Brown trout, *Salmo trutta*	1.613	-

a Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
b Freshwater Genus Mean Acute Values and Freshwater Species Mean Acute Values are at a hardness of 50 mg/L.
c Geometric mean of two values in Table 2e.
d Geometric mean of three values in Table 2e.
e Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

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

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
54	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000	-
53	50,000	Sheepshead minnow, *Cyprinodon variegatus*	50,000	-
52	27,992	Amphipod, *Eohaustoris estuarius*	27,992	-
51	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000	-
50	21,238	Fiddler crab, *Uca pugilator*	21,238	-
49	19,550	Mummichog, *Fundulus heteroclitus*	18,200	-
		Striped killifish, *Fundulus majalis*	21,000	-
48	19,170	Mud snail, *Nassarius obsoletus*	19,170	-
47	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297	-
46	12,836	Polychaete worm, *Neanthes arenaceodentata*	12,836	-
45	11,000	Shiner perch, *Cymatogaster aggregata*	11,000	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
44	>10,200	Squid, *Loligo opalescens*	>10,200	-
43	10,000	Oligochaete worm, *Limnodriloides verrucosus*	10,000	-
42	7,400	Sand dollar, *Dendraster excentricus*	7,400	-
41	7,120	Isopod, *Limnoria tripunctata*	7,120	-
40	7,079	Striped mullet, *Mugil cephalus*	7,079	-
39	6,895	Polychaete worm, *Nereis grubei*	4,700	-
		Sand worm, *Nereis virens*	10,114	-
38	6,700	Amphipod, *Diporeia spp.*	6,700	-
37	6,600	Oyster drill, *Urosalpinx cinerea*	6,600	-
36	4,100	Green crab, *Carcinus maenas*	4,100	-
35	3,500	Amphipod, *Marinogammarus obtusatus*	3,500	-
34	2,900	Amphipod, *Ampelisca abdita*	2,900	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
33	2,600	Polychaete worm, *Pectinaria californiensis*	2,600	-
32	2,594	Blue crab, *Callinectes sapidus*	2,594	-
31	2,413	Starfish, *Asterias forbesi*	2,413	-
30	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708	-
29	1,672	Soft-shell clam, *Mya arenaria*	1,672	-
28	1,500	Coho salmon, *Oncorhynchus kisutch*	1,500	-
27	1,480	Bay scallop, *Argopecten irradians*	1,480	-
26	1,228	Grass shrimp, *Palaemonetes pugio*	1,983	-
		Grass shrimp, *Palaemonetes vulgaris*	760	-
25	1,170	Amphipod, *Grandidierella japonica*	1,170	-
24	1,073	Blue mussel, *Mytilus edulis*	1,073	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
23	948.7	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800	-
		Purple sea urchin, *Strongylocentrotus purpuratus*	500	-
22	930.6	Pacific oyster, *Crassostrea gigas*	227.9	-
		Eastern oyster, *Crassostrea virginica*	3,800	-
21	929.3	Amphipod, *Corophium insidiosum*	929.3	-
20	800	Rivulus, *Rivulus marmoratus*	800	-
19	794.5	Copepod, *Nitocra spinipes*	794.5	-
18	779.8	Atlantic silverside, *Menidia menidia*	779.8	-
17	716.2	Amphipod, *Elasmopus bampo*	716.2	-
16	645.0	Hermit crab, *Pagurus longicarpus*	645.0	-
15	630.0	Amphipod, *Chelura terebrans*	630.0	-
14	590.5	Amphipod, *Leptocheirus plumulosus*	590.5	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
13	410.0	Isopod, *Jaeropsis sp.*	410.0	-
12	320.0	Sand shrimp, *Crangon septemspinosa*	320.0	-
11	310.5	Pink shrimp, *Penaeus duorarum*	310.5	-
10	235.7	Rock crab, *Cancer irroratus*	250.0	-
		Dungeness crab, *Cancer magister*	222.3	-
9	224	Copepod, *Amphiascus tenuiremis*	224	-
8	>200	Cabezon, *Scorpaenichthys marmoratus*	>200	-
7	200	Polychaete worm, *Capitella capitata*	200	-
6	147.7	Copepod, *Eurytemora affinis*	147.7	-
5	130.7	Copepod, *Acartia clausi*	144	-
		Copepod, *Acartia tonsa*	118.7	-
4	110	Mysid, *Mysidopsis bigelowi*	110	15.40

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
3	78	American lobster, *Homarus americanus*	78	-
2	75.0	Striped bass, *Morone saxatilis*	75.0	-
1	41.29	Mysid, *Americamysis bahia*	41.29	5.384[c]

a Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
b Freshwater Genus Mean Acute Values and Freshwater Species Mean Acute Values are at a hardness of 50 mg/L.
c Geometric mean of two values in Table 2e.
d Geometric mean of three values in Table 2e.
e Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3c. Ranked Freshwater Genus Mean Chronic Values

Rank[a]	Genus Mean Chronic Value (µg/L)	Species	Species Mean Chronic Value (µg/L)[b]	Species Mean Acute-Chronic Ratio
16	27.17	Cladoceran, *Ceriodaphnia dubia*	27.17	-
15	>23.63	Blue Tilapia, *Oreochromis aurea*	>23.63	-
14	20.74	Oligochaete, *Aeolosoma headleyi*	20.74	-
13	17.38	Bluegill, *Lepomis macrochirus*	17.38[c]	423.7
12	16.38	Fathead minnow, *Pimephales promelas*	16.38[c]	13.13[c]
11	8.124	Smallmouth bass, *Micropterus dolomieui*	8.124	-
10	8.092	Northern pike, *Esox lucius*	8.092	-
9	7.804	White sucker, *Catostomus commersoni*	7.804	-
8	6.296	Atlantic salmon, *Salmo salar*	7.922	-
		Brown trout, *Salmo trutta*	5.004[c]	-
7	5.318	Flagfish, *Jordanella floridae*	5.318[d]	433.8
6	4.820	Snail, *Aplexa hypnorum*	4.820[c]	20.76[c]
5	4.624	Brook trout, *Salvelinus fontinalis*	2.643[d]	-
		Lake trout, *Salvelinus namaycush*	8.088	-
4	2.804	Midge, *Chironomus tentans*	2.804	-
3	2.443	Coho salmon, *Oncorhynchus kisutch*	4.265[c]	-
		Rainbow trout, *Oncorhynchus mykiss*	1.308	-
		Chinook salmon, *Oncorhynchus tshawytscha*	2.612	0.9021

Table 3c. Ranked Freshwater Genus Mean Chronic Values (Continued)

Rank[a]	Genus Mean Chronic Value ($\mu g/L$)	Species	Species Mean Chronic Value ($\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
2	<0.3794[f]	Cladoceran, *Daphnia magna*	<0.3794[e]	104.3[d]
		Cladoceran, *Daphnia pulex*	6.167[f]	-
1	0.2747	Amphipod, *Hyalella azteca*	0.2747	-

a Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.
b Genus Mean Chronic Values and Species Mean Chronic Values are at a hardness of 50 mg/L.
c Geometric mean of two values.
d Geometric mean of three values.
e Geometric mean of five values.
f Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3d. Freshwater and Saltwater Cadmium Criteria Values

Fresh water

CMC:

Final Acute Value = 2.763 µg/L (calculated at a hardness of 50 mg/L from Genus Mean Acute Values)

Final Acute Value = 2.108 µg/L (lowered to protect rainbow trout at a hardness of 50 mg/L; see text)

Criterion Maximum Concentration = (2.108 µg/L) /2 = 1.054 µg/L Total Cadmium (at a hardness of 50 mg/L)

Pooled Slope = 1.0166 (see Table 1)

ln (Criterion Maximum Intercept) = ln(1.054) - [slope x ln(50)]

= 0.0526 - (1.0166 x 3.912) = -3.924

Criterion Maximum Concentration for Total Cadmium (at a hardness of 50 mg/L) = $e^{(1.0166[\ln(\text{hardness})]-3.924)}$

Criterion Maximum Concentration for Dissolved Cadmium (at 50 mg/L hardness) = 0.973 $[e^{(1.0166[\ln(\text{hardness})]-3.924)}]$

CCC:

Total Cadmium Freshwater Final Chronic Value = 0.1618 µg/L (see text)

Slope = 0.7409 (see text)

ln (Final Chronic intercept) = ln (0.1618) - [slope x ln(50)]

= -1.821 - (0.7409 x 3.912) = -4.719

Total Cadmium Freshwater Final Chronic Value (at a hardness of 50 mg/L) = $e^{(0.7409\ [\ln(\text{hardness})]-4.719)}$

Dissolved Cadmium Freshwater Final Chronic Value (at 50 mg/L hardness) = 0.938 $[e^{(0.7409\ [\ln(\text{hardness})]-4.719)}]$

Salt water

CMC:

Total Cadmium Final Acute Value = 80.55 µg/L

Total Cadmium Criterion Maximum Concentration = (80.55 µg/L)/2 = 40.28 µg/L

Dissolved Cadmium Criterion Maximum Concentration = 0.994 (40.28 µg/L) = 40 µg/L

Final Acute-Chronic Ratio = 9.106 (see text)

CCC:

Total Cadmium Final Chronic Value = (80.55 µg/L)/9.106 = 8.846 µg/L

Dissolved Cadmium Final Chronic Value = 0.994 (8.846 µg/L) = 8.8 µg/L

Table 3d. Freshwater and Saltwater Cadmium Criteria Values (Continued)

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 55

Rank	GMAV	lnGMAV	$(\ln GMAV)^2$	P=R/(n+1)	SQRT(P)
4	3.836	1.345	1.808	0.0714	0.2673
3	2.925	1.073	1.152	0.0536	0.2315
2	1.963	0.6745	0.4549	0.0357	0.1890
1	1.613	0.4781	0.2286	0.0179	0.1336
Sum:		**3.571**	**3.644**	**0.1786**	**0.8213**

S =	6.781
L =	-0.4997
A =	1.017
Calculated FAV =	**2.764**

Calculated Saltwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 54

Rank	GMAV	lnGMAV	$(\ln GMAV)^2$	P=R/(n+1)	SQRT(P)
4	110	4.700	22.095	0.0727	0.2697
3	78	4.357	18.981	0.0545	0.2335
2	75.0	4.317	18.641	0.0364	0.1907
1	41.29	3.721	13.843	0.0182	0.1348
Sum:		**17.095**	**73.559**	**0.1818**	**0.8288**

S =	7.012
L =	2.821
A =	4.389
Calculated FAV =	**80.55**

Table 3d. Freshwater and Saltwater Cadmium Criteria Values (Continued)

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMAVs in Data Set = 16

Rank	GMAV	lnGMAV	$(\ln GMAV)^2$	P=R/(n+1)	SQRT(P)
4	2.804	1.031	1.063	0.2353	0.4851
3	2.443	0.8932	0.7979	0.1765	0.4201
2	0.3794	-0.9692	0.9393	0.1176	0.3430
1	0.2747	-1.292	1.669	0.0588	0.2425
Sum:		**-0.3370**	**4.470**	**0.5882**	**1.491**

S =	11.65
L =	-4.428
A =	-1.822
Calculated FCV =	**0.1618**

Table 4a. Toxicity of Cadmium to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total $\mu g/L$)	Reference
				FRESHWATER SPECIES			
Diatom, *Asterionella formosa*	-	-	-	-	Factor of 10 growth rate decrease	2	Conway 1978
Diatom, *Scenedesmus quadracauda*	-	Cadmium chloride	-	-	Reduction in cell count	6.1	Klass et al. 1974
Diatom, *Nitzschia costerium*	-	Cadmium chloride	-	-	96-hr EC50	480	Rachlin et al. 1982
Diatom, *Navicula incerta*	-	Cadmium chloride	-	-	96-hr EC50	310	Rachlin et al. 1982
Green alga, *Scenedesmus obliquus*	-	Cadmium chloride	-	-	39% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982
Alga, *Euglena gracilis*	-	Cadmium chloride	-	-	Morphological abnormalities	5,000	Nakano et al. 1980
Alga, *Euglena gracilis anabaena*	-	Cadmium nitrate	-	-	Cell division inhibition	20,000	Nakano et al. 1980
Green alga, *Ankistrodesmus falcatus*	-	Cadmium chloride	-	-	58% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982
Blue alga, *Microcystis aeruginosa*	-	Cadmium nitrate	-	-	incipient inhibition	70	Bringmann 1975; Bringmann and Kuhn 1976, 1978a,b
Green alga. *Scenedesmus quadricauda*	-	Cadmium nitrate	-	-	incipient inhibition	310	Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980b
Green alga, *Chlorella saccharophila*	-	Cadmium chloride	-	-	96-hr EC50	105	Rachlin et al. 1984
Alga, *Chlorococcum* sp.	-	Cadmium chloride	-	-	42% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982

Table 4a. Toxicity of Cadmium to Freshwater Plants (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
				FRESHWATER SPECIES			
Green alga, *Chlorella pyrenoidosa*	-	-	-	-	Reduction in growth	250	Hart and Scaife 1977
Green alga, *Chlorella vulgaris*	-	-	-	-	Reduction in growth	50	Hutchinson and Stokes 1975
Alga, *Chara vulgaris*	S, M, T	Cadmium sulfate	-	7 days	Lethal dose	56.2	Heumann 1987
Alga, *Chara vulgaris*	S, M, T	Cadmium sulfate	-	14 days	EC50 growth	9.5	Heumann 1987
Green alga, *Chlamydomonas reinhardi*	F, M, T	Cadmium chloride	24	4 days 7 days 10 days	EC50 (cell density) EC50 (cell density) EC50 (cell density)	203 130 99	Schafer et al. 1993
Green alga, *Clorella vulgaris*	-	Cadmium chloride	-	-	50% reduction in growth	60	Rosko and Rachlin 1977
Green alga, *Clorella vulgaris*	-	Cadmium chloride	50	-	96-hr EC50 (growth inhibition)	3,700	Canton and Slooff 1982
Green alga, *Selenastrum capricornutum*	-	Cadmium chloride	-	-	Reduction in growth	50	Bartlett et al. 1974
Green alga, *Selenastrum capricornutum*	-	Cadmium nitrate	-	-	Reduction in growth	255	Slooff et al. 1983
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	-	4 days	IC 50 growth	10,500	Bozeman et al. 1989
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	-	4 days	EC50 growth	23.2	Thellen et al. 1989
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	171	4 days	EC50 growth	130	Versteeg 1990

Table 4a. Toxicity of Cadmium to Freshwater Plants (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total μg/L)	Reference
				FRESHWATER SPECIES			
Alga, *Anabaena flos-aquae*	-	Cadmium chloride	-	-	96-hr EC50	120	Rachlin et al. 1984
Algae (mixed spp.)	-	Cadmium chloride	11.1	-	Significant reduction in population	5	Giesy et al. 1979
Fern, *Salvina natans*	-	Cadmium nitrate	-	-	Reduction in number of fronds	10	Hutchinson and Czyrska 1972
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	-	-	32-day EC50 (root weight)	7,400	Stanley 1974
Duckweed, *Lemna gibba*	S, M, T	Cadmium nitrate	-	7 days	EC50 growth	800	Devi et al. 1996
Duckweed, *Lemna minor*	S, U	-	-	4 days	EC50 growth	200	Wang 1986
Duckweed, *Lemna minor*	R, M, T	Cadmium chloride	39	4 days	Reduced chlorophyll	54	Taraldsen and Norberg-King 1990
Duckweed, *Lemna valdiviana*	-	Cadmium nitrate	-	-	Reduction in number of fronds	10	Hutchinson and Czyrska 1972
Duckweed, *Spirodela polyrhiza*	R, U	Cadmium sulfate	-	28 days	LOEC growth	7.63	Sajwan and Ornes 1994

a S=static: R=renewal; F=flow through; U=unmeasured; M=measured; T=total metal conc. measured; D=dissolved metal conc. measured.
b Results are expressed as cadmium, not as the chemical.

Table 4b. Toxicity of Cadmium to Saltwater Plants

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result[b] (Total μg/L)	Reference
			SALTWATER SPECIES				
Kelp, *Laminana saccharina*	-	Cadmium chloride	-	-	8-day EC50 (growth rate)	860	Markham et al. 1980
Diatom, *Asterionella japonica*	-	Cadmium chloride	-	-	72-hr EC50 (growth rate)	224.8	Fisher and Jones 1981
Diatom, *Ditylum brightwellii*	-	Cadmium chloride	-	-	5-day EC50 (growth)	60	Canterford and Canterford 1980
Diatom, *Phaeodactylum tricornutum*	S, U	Cadmium chloride	35	4 days	EC50 growth	22,390	Torres et al. 1998
Diatom, *Thalassiosira pseudonana*	-	Cadmium chloride	-	-	96-hr EC50 (growth rate)	160	Gentile and Johnson, 1982
Diatom, *Skeletonema costatum*	-	Cadmium chloride	-	-	96-hr EC50 (growth rate)	175	Gentile and Johnson 1982
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporophyte growth	24.9	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporangia production	>189	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced female growth	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Stopped sexual reproduction	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	14 days	NOEC sexual reproduction	77	Thursby and Steele 1986

a S=static: R=renewal; F=flow through; U=unmeasured; M=measured; T= total metal conc. measured; D=dissolved metal conc. measured.
b Results are expressed as cadmium, not as the chemical.

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Aufwuchs (attached microscopic plants and animals	-	Cadmium chloride	-	-	365	720	Giesy et al. 1979
Aufwuchs (attached microscopic plants and animals	-	Cadmium chloride	-	-	365	580	Giesy et al. 1979
Duckweed, *Lemna valdiviana*	Whole plant	Cadmium nitrate	-	-	21	603	Hutchinson and Czyrska 1972
Fern, *Salvinia natans*	Whole plant	Cadmium nitrate	-	-	21	960	Hutchinson and Czyrska 1972
Snail, *Physa integra*	Whole body	Cadmium chloride	-	-	28	1,750	Spehar et al. 1978
Snail, *Viviparus georgianus*	Soft tissue (1 yr old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	71[b] 74[b] 109[b]	Tessier et al. 1994a
	Soft tissue (2 yrs old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	28[b] 42[b] 60[b]	
	Soft tissue (3 yrs old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	27[b] 42[b] 26[b]	
Snail, *Viviparus georgianus*	Soft tissue (1 yr old)	Cadmium chloride	-	10 50	60 60	6,910[b] 2,238[b]	Tessier et al. 1994b
	Soft tissue (2 yrs old)	Cadmium chloride	-	10 50	60 60	1,758[b] 758[b]	
	Soft tissue (3 yrs old)	Cadmium chloride	-	10 50	60 60	1,258[b] 617[b]	

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Mussel, *Elliptio complanata*	Soft tissue (0-74 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	15[b] 16[b] 28[b]	Tessier et al. 1994a
	Soft tissue (74-86 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	16[b] 16[b] 14[b]	
	Soft tissue (86-100 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	8[b] 7[b] 8[b]	
Mussel, *Elliptio complanata*	Soft tissue (0-74 mm length)	Cadmium chloride	-	10 50	60 60	1,256[b] 918[b]	Tessier et al. 1994b
	Soft tissue (74-86 mm)	Cadmium chloride	-	10 50	60 60	945[b] 613[b]	
	Soft tissue (86-100 mm)	Cadmium chloride	-	10 50	60 60	574[b] 254[b]	
Asiatic clam, *Corbicula fluminea*	Whole body	Cadmium sulfate	-	-	28	3,770	Graney et al. 1983
Asiatic clam, *Corbicula fluminea*	Whole body	Cadmium sulfate	-	-	28	1,752	Graney et al. 1983
Cladoceran, *Daphnia magna*	Whole body	Cadmium sulfate	-	-	2-4	320	Poldoski 1979
Cladoceran, *Daphnia magna*	Whole body	Cadmium sulfate	-	-	7	484[b]	Winner 1984
Crayfish, *Orconectes propinquus*	Whole body	-	-	-	8	184	Gillespie et al. 1977

Table 5a. **Bioaccumulation of Cadmium by Freshwater Organisms (Continued)**

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Mayfly, *Ephemeroptera* sp.	Whole body	Cadmium chloride	-	-	365	1,630	Giesy et al. 1979
Mayfly, *Ephemeroptera* sp.	Whole body	Cadmium chloride	-	-	365	3,520	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Whole body	Cadmium chloride	-	-	365	736	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Whole body	Cadmium chloride	-	-	365	680	Giesy et al. 1979
Damselfly, *Ischnura* sp.	Whole body	Cadmium chloride	-	-	365	1,300	Giesy et al. 1979
Damselfly, *Ischnura* sp.	Whole body	Cadmium chloride	-	-	365	928	Giesy et al. 1979
Stonefly, *Pteronarcys dorsata*	Whole body	Cadmium chloride	-	-	28	373	Spehar et al. 1978
Beetle, Dytiscidae	Whole body	Cadmium chloride	-	-	365	164	Giesy et al. 1979
Beetle, Dytiscidae	Whole body	Cadmium chloride	-	-	365	260	Giesy et al. 1979
Caddisfly, *Hydropsyche betteni*	Whole body	Cadmium chloride	-	-	28	4,190	Spehar et al. 1978
Caddisfly, *Hydropsyche* sp.	Whole body	Cadmium chloride	-	-	2-8	228.2[b]	Dressing et al. 1982
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	-	-	365	936	Giesy et al. 1979

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	-	-	365	662	Giesy et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	-	-	365	2,200	Giesy et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	-	-	365	1,830	Giesy et al. 1979
Midge, *Chironomus riparius*	Whole body	-	-	10,000	28	1,370[b]	Timmermans et al. 1992
Lake whitefish, *Coregonus clupeaformis*	Whole body	Cadmium chloride	82.5	2.07	72	42	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Whole body	-	-	-	140	540	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	Whole body	Cadmium chloride	-	-	70	33	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Whole body	Cadmium chloride	82.5	3.39	72	55	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Muscle	Cadmium sulfate	250	1.8	231	333	Brown et al. 1994
				3.4	231	294	
				5.5	231	509	
				1.8	455	89	
				3.4	455	182	
				5.5	455	127	

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Atlantic salmon, *Salmo salar*	Whole body (egg)	Cadmium chloride	-	0.87 (pH=6.8)	91	229	Peterson et al. 1985
				1.74 (pH=6.8)	91	176	
				1.01 (pH=4.5)	91	4	
				2.09 (pH=4.5)	91	7	
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	490	3	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	84	151	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	93	22	Sangalang and Freeman 1979
Mosquitofish, *Gambusia affinis*	Whole body (estimated steady state)	Cadmium chloride	-	-	180	2,213	Giesy et al. 1979
Mosquitofish, *Gambusia affinis*	Whole body (estimated steady state)	Cadmium chloride	-	-	180	1,891	Giesy et al. 1979
Guppy, *Poecilia reticulata*	Whole body	-	-	-	32	280	Canton and Slooff 1982

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
FRESHWATER SPECIES							
Bluegill sunfish, *Lepomis macrochirus*	Whole body	Cadmium chloride	134	0.8	28	113	Cope et al. 1994
				1.8	28	78	
				2.2	28	86	
				2.8	28	68	
				3.6	28	67	
				4.4	28	66	
				5.2	28	69	
				6.2	28	50	
				7.7	28	48	
				8.4	28	62	
				13.2	28	55	
				16.1	28	37	
				19.7	28	34	
				32.3	28	41	
Blue tilapia, *Tilapia aurea*	Muscle	Cadmium nitrate	145	6.8	112	17.6	Papoutsoglou and Abel 1988
				14	112	16.4	
				28	112	25.7	
				52	112	17.7	
African clawed frog, *Xenopus laevis*	Whole body	-	-	-	100	130	Canton and Slooff 1982
Mallard duck, *Anas platyrhynchos*	Kidney tubule degeneration, Testis weight reduction, inhibited spermatozoa production	-	-	200 mg/kg[c] (in food)	90	-	White and Finley 1978a,b; White et al. 1978

a Results are based on cadmium, not the chemical.
b Bioconcentration factor was converted from dry weight to wet weight basis.
c More recent information may be available for this species.

Table 5b. Bioaccumulation of Cadmium by Saltwater Organisms

Species	Tissue	Chemical	Salinity (g/kg)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			SALTWATER SPECIES				
Polychaete worm, *Ophryotrocha diadema*	Whole body	Cadmium chloride	-	-	64	3,160	Klockner 1979
Blue mussel, *Mytilus edulis*	Soft parts	Cadmium chloride	-	-	28	113	George and Coombs1977
Blue mussel, *Mytilus edulis*	Soft parts	Cadmium chloride	-	-	35	306	Phillips 1976
Bay scallop, *Argopecten irradians*	Muscle	Cadmium chloride	-	-	42	2,040	Pesch and Stewart 1980
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium chloride	-	-	280	2,150	Zaroogian and Cheer 1976
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium chloride	-	-	280	1,830	Zaroogian 1979
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium nitrate	-	-	98	1,220	Schuster and Pringle 1969
Soft-shell clam, *Mya arenaria*	Soft parts	Cadmium nitrate	-	-	70	160	Pringle et al. 1968
Pink shrimp, *Penaeus duorarum*	Whole body	Cadmium chloride	-	-	30	57	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Whole body	Cadmium chloride	-	-	42	22	Pesch and Stewart 1980
Grass shrimp, *Paleomonetes pugio*	Whole body	Cadmium chloride	-	-	28	203	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes vulgaris*	Whole body	Cadmium chloride	-	-	28	307	Nimmo et al. 1977b

Table 5b. Bioaccumulation of Cadmium by Saltwater Organisms (Continued)

Species	Tissue	Chemical	Salinity (g/kg)	Concentration in Water (µg/L)[a]	Duration (days)	BCF or BAF	Reference
			SALTWATER SPECIES				
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	-	-	68	5	Wright 1977
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	-	-	40	7	Jennings and Rainbow 1979a

a Results are based on cadmium, not the chemical.
b Bioconcentration factor was converted from dry weight to wet weight basis.
c More recent information may be available for this species.

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Mixed natural fungi and bacterial colonies on leaf litter	-	Cadmium chloride	10.7	28 wk	Inhibition of leaf decomposition	5	15.67	-	Giesy 1978
Plankton	-	-	-	2 wk	Reduced crustacean, zooplankton, and rotifers	1-3	-	-	Marshall et al. 1981, 1983
Mixed algal species	S, U	Cadmium chloride	-	10 days	Growth inhibition	50	-	-	Lasheen et al. 1990
Phytoplankton community	S, M, T	Cadmium chloride	-	150 days	NOEC biomas and photosynthesis	0.185	-	-	Findlay et al. 1996
Duckweed, *Lemna minor*	R, U	-	-	10 days	EC50 (frond production)	191	-	-	Smith and Kwan 1989
Duckweed, *Spirodela punctata*	S, M, T	-	-	30 days	Reduced growth rate	25	-	-	Outridge 1992
Water fern, *Salvinia minima*	S, M, T	-	-	30 days	Reduced growth rate	10	-	-	Outridge 1992
Cyanophyceae, *Microcystis aeroginosa*	S, U	Cadmium chloride	-	24 hr	EC50 growth	0.56	-	-	Guanzon et al. 1994
Cyanobacterium, *Anacystis nidulans*	S, U	Cadmium chloride	-	14 days	No growth	50,000	-	-	Lee et al. 1992
Green alga, *Selenastrum capricornutum*	R, U	Cadmium chloride	24.2	72 hr	EC50 (cell counts)	20.6	43.08	-	Radetski et al. 1995

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	24.2	72 hr	EC50 (cell counts)	42.7	89.29	-	Radetski et al. 1995
Green alga, *Chlamydomonas reinhardi*	S, U	Cadmium chloride	-	72 hr	EC50 (growth)	789	-	-	Schafer et al. 1994
Green alga, *Scenedesmus dimorphus*	S, U	Cadmium nitrate	11.3	48 hr	LC50 (density)	63	285.7	-	Ghosh et al. 1990
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	20 days	LC50	9	-	-	Fargasova 1993
Green alga, *Selenastrum capricornutum*	S, M, T	Cadmium nitrate	-	120 hr	LOEC growth	30	-	-	Thompson and Couture 1991
Green alga, *Selenastrum capricornutum*	S, U	-	-	72 hr	EC50 (cell number)	164	-	-	Van der Heever and Grobbelaar 1996
		-	-		EC50 (chlorophyll)	97	-	-	
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	24 hr	EC50 growth	1.9	-	-	Guanzon et al. 1994
Green alga, *Stichococcus bacillaris*	S, U	Cadmium chloride	-	96 hr	Reduced growth	5,000	-	-	Skowronski et al. 1985
Green alga, *Chlorella vulgaris*	S, U	Cadmium chloride	-	72 hr	Reduced progeny formation	100	-	-	Wilczok et al. 1994

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Green alga, *Chlorella vulgaris*	S, U	Cadmium nitrate	-	72 hr	EC50 growth	50,000	-	-	Wren and McCarroll 1990
Green alga, *Scenedesmus quadricauda*	-	Cadmium chloride	-	96 hr	Incipient inhibition (river water)	100	-	-	Bringmann and Kuhn 1959a,b
Bacteria, *Escherichia coli*	-	Cadmium chloride	-	-	Incipient inhibition	150	-	-	Bringmann and Kuhn 1959a
Bacteria, *Salmonella typhimurium*	-	Cadmium chloride	50	8 hr	EC50 (growth inhibition)	10,400	10,400	-	Canton and Slooff 1982
Bacteria, *Pseudomonas putida*	-	Cadmium chloride	-	16 hr	Incipient inhibition	80	-	-	Bringmann and Kuhn 1976, 1977a, 1979, 1980b
Bacteria, (6 species)	-	Cadmium chloride	-	18 hr	Reduced growth	5,000 100,000	-	-	Seyfreid and Horgan 1983
Protozoan community	S, M, T	Cadmium chloride	70	2 days	EC50 (number of species)	4,600	3,267	-	Niederlehner et al. 1985
				28 days	EC20 (colonization)	1	-	-	
Protozoan community	S, U	Cadmium chloride	-	240 hr	Reduced biomas	1	-	-	Fernandez-Leborans and Novillo-Villajos 1993

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Protozoan, *Entosiphon sulcatum*	-	Cadmium nitrate	-	72 hr	Incipient inhibition	11	-	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980b, 1981
Protozoan, *Microregma heterostoma*	-	Cadmium chloride	-	28 hr	Incipient inhibition	100	-	-	Bringmann and Kuhn 1959b
Protozoan, *Chilomonas paramecium*	-	Cadmium nitrate	-	48 hr	Incipient inhibition	160	-	-	Bringmann et al. 1980
Protozoan, *Uronema parduezi*	-	Cadmium nitrate	-	20 hr	Incipient inhibition	26	-	-	Bringman and Kuhn 1980a, 1981
Protozoan, *Spirostomum ambiguum*	S, U	Cadmium chloride	28 250	24 hr 24 hr	LC50 LC50	78.1 5,270	140.8 1,026	- -	Nalecz-Jawecki et al. 1993
Protozoan, *Spirostomum ambiguum*	S, U	Cadmium nitrate	-	48 hr	LC50	168	-	-	Nalecz-Jawecki and Sawicki 1998
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	72 hr	Growth inhibition	3,372	-	-	Krawczynska et al. 1989
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	96 hr	EC50 growth	1,045	-	-	Schafer et al. 1994
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium acetate	-	30 min	Complete mortality	56,205	-	-	Larsen and Svensmark 1991
Ciliate, *Colpidium campylum*	S, U	Cadmium sulfate	-	24 hr	EC50 growth	75	-	-	Dive et al. 1989

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	9 hr	IC50 growth	3,000	-	-	Sauvant et al. 1995
Ciliate, *Spirostomum teres*	S, U	Cadmium chloride	-	24 hr	LC50	1,950	-	-	Twagilimana et al. 1998
Hydra, *Hydra oligactis*	-	Cadmium nitrate	-	48 hr	LC50	583	-	-	Slooff 1983: Slooff et al. 1983
Hydra, *Hydra littoralis*	-	Cadmium chloride	70	12 days	Reduced growth	20	15.59	-	Santiago-Fandino 1983
Planarian, *Dendrocoelum lacteum*	R, M, T	Cadmium chloride	122.8	48 hr	LC50	46,000	18,452	-	Brown and Pascoe 1988
Planarian, *Dugesia lugubris*	-	Cadmium nitrate	-	48 hr	LC50	>20,000	-	-	Slooff 1983
Mixed macro invertebrates	-	Cadmium chloride	11.1	52 wk	Reduced taxa	5	15.25	-	Giesy et al. 1979
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	72 hr	Chronic value (asexual reproduction)	20	12.94	-	Snell and Carmona 1995
					Chronic Value (sexual reproduction)	20	12.94	-	
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	48 hr	EC50	70	38.51	-	Snell and Moffat 1992
					Chronic value	60	38.82	-	
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	24 hr	LC50	1,300	715.2	-	Snell et al. 1991a

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total μg/L)[b]	Result Adjusted to TH=50 (Total μg/L)	Result Adjusted to TH=50 (Dissolved μg/L)	Reference
					FRESHWATER SPECIES				
Rotifer, *Brachionus rubens*	S, U	Cadmium chloride	80-100	24 hr	LC50	810	445.6	-	Snell and Persoone 1989a
					NOEC (survival)	280	154.1	-	
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium chloride	170	35 min	NOEC (ingestion rate)	250	72.05	-	Juchelka and Snell 1994
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	48 hr	EC50	10	5.502	-	Radix et al. 1999
Mixed zooplankton community	F, M, T	-	-	14 days	60% reduced biomass	1	-	-	Lawrence and Holoka 1987
Tubificid worm, *Tubifex tubifex*	-	Cadmium chloride	224	48 hr	LC50	320,000	69,672	-	Qureshi et al. 1980
Tubificid worm, *Tubifex tubifex*	R, U	Cadmium chloride	245	96 hr	LC50	47,530	9,447	-	Khangarot 1991
Worm, *Lumbriculus variegatus*	F, M, T	Cadmium chloride	44-47	10 days	LC50	158	169.4	-	Phipps et al. 1995
Worm, *Pristina* sp.	-	Cadmium chloride	11.1	52 wk	Population reduction	5	15.25	-	Giesy et al. 1979
Worm, *Pristina leidyi*	S, M, T	Cadmium chloride	95	48 hr	LC50	215	112.0	-	Smith et al. 1991
Nematode, *Caenorhabditis elegans*	S, U	Cadmium chloride	-	96 hr	LC50 (fed)	61	-	-	Williams and Dusenbery 1990
Leech (cocoon), *Nephelopsis obscura*	S, M, T	Cadmium chloride	-	96 hr	LC50	832.6	-	-	Wicklum et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Snail, *Amnicola limosa*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	6,350 (pH=3.5)	21,164	-	Mackie 1989
						3,800 (pH=4.0)	12,665	-	
						2,710 (pH=4.5)	9,032	-	
Snail, *Lymnaea stagnalis*	-	Cadmium chloride	-	48 hr	LC50	583	-	-	Slooff 1983; Slooff et al. 1983
Snail, *Physa integra*	-	Cadmium chloride	44-58	28 days	LC50	10.4	10.25	-	Spehar et al. 1978
Snail, *Vivpara bengalensis*	S, U	Cadmium chloride	140-190	96 hr	LC50	1,550	460.5	-	Gadkari and Marathe 1983
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	39	48 hr	LC50	57	73.38	-	Keller and Zam 1991
			80-100	48 hr	LC50	137	75.37	-	
Zebra mussel, *Dreissena polymorpha*	R, M, T	Cadmium chloride	150	48 hr	EC50	388	127.0	- -	Kraak et al. 1994a
Zebra mussel, *Dreissena polymorpha*	R, M, T	Cadmium chloride	268	10 wk	LOEC filtration rate	9	2.594	-	Kraak et al. 1992b
				11 wk	EC50	130	37.47	-	
Bivalve, *Pisidium casertanum*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	1,370 (pH=3.5)	4,566	-	Mackie 1989
						480 (pH=4.0)	1,600	-	
						700 (pH=4.5)	2,333	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Bivalve, *Pisidium compressum*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	2,080 (pH=3.5)	6,932	-	Mackie 1989
						700 (pH=4.0)	2,333	-	
						360 (pH=4.5)	1,200	-	
Cladoceran (<24 hr) *Ceriodaphnia dubia*	R,M,T	Cadmium nitrate	100	48 hr	LC50	27.3 (High TOC)	13.49	-	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia*	R, U	Cadmium sulfate	169	7 days	Chronic value reproduction	<14	<5.679	-	Masters et al. 1991
Cladoceran, *Ceriodaphnia dubia*	S, U	Cadmium chloride	80-100	1 hr	EC50 feeding inhibition	54	29.71	-	Bitton et al. 1996
Cladoceran, *Ceriodaphnia dubia*	S, U	Cadmium chloride	80-100	1 hr	EC50 feeding inhibition	76.2	41.92	-	Lee et al. 1997
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, M, T	Cadmium nitrate	280-300	48 hr	LC50 (fed)	560	93.78	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	80	48 hr	LC50	49.5	30.70	-	Hockett and Mount 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	172	48 hr	LC50	221	62.94	-	Hockett and Mount 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, D	Cadmium sulfate	160-180	120 min	Reduced mobility	2,500	720.5	-	Brent and Herricks 1998
Cladoceran, *Ceriodaphnia dubia*	R, U	Cadmium chloride	80-100	7 days	Chronic value	1.4	0.9057	-	Zuiderveen and Birge 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium nitrate	80-100	48 hr	LC50	78.2 (fed)	43.02	-	Nelson and Roline 1998
Cladoceran, *Ceriodaphnia dubia*	R, U	Cadmium sulfate	90	10 days	NOEC reproduction	0.5	0.3235	-	Winner 1988
Cladoceran, *Ceriodaphnia reticulata*	S, U	-	45	48 hr	LC50	66 (fed bacterial suspension)	73.46	-	Mount and Norberg 1984
Cladoceran, *Ceriodaphnia reticulata*	S, M	Cadmium chloride	55-79	48 hr	LC50	129 (High TOC)	95.80	-	Spehar and Carlson 1984a,b
Cladoceran (<6 hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	79.4	19.40	-	Hall et al. 1986
Cladoceran, *Ceriodaphnia reticulata*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	1,900	2,539	-	Sharma and Selvaraj 1994
Cladoceran, *Daphnia carinata*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	280	374.1	-	Sharma and Selvaraj 1994
Cladoceran, *Daphnia galeata mendotae*	-	Cadmium chloride	-	22 wk	Reduced biomass	4.0	-	-	Marshall 1978a
Cladoceran, *Daphnia galeata mendotae*	-	Cadmium chloride	-	15 days	Reduced rate of increase	5.0	-	-	Marshall 1978b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	-	Cadmium chloride	-	48 hr	EC50 (river water)	100	-	-	Bringmann and Kuhn 1959a,b
Cladoceran, *Daphnia magna*	-	Cadmium chloride	45	21 days	Reproductive impairment	0.17	0.184	-	Biesinger and Christensen 1972
Cladoceran, *Daphnia magna*	-	Cadmium chloride	163	72 hr	LC50	15.4 (14-17)	4.632	-	Debelak 1975
Cladoceran, *Daphnia magna*	-	Cadmium nitrate	-	24 hr	LC50	600	-	-	Bringmann and Kuhn 1977b
Cladoceran (3-5 days), *Daphnia magna*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	224	-	-	Braginskly and Shcherban 1978
					(15°C)	224	-	-	
					(25°C)	12	-	-	
					(30°C)	0.1	-	-	
Cladoceran (adult), *Daphnia magna*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	479	-	-	Braginskly and Shcherban 1978
					(15°C)	187	-	-	
					(25°C)	10.2	-	-	
					(30°C)	2.4	-	-	
Cladoceran, *Daphnia magna*	-	Cadmium nitrate	200	24 hr	EC50	160	39.09	-	Bellavera and Gorbi 1981
Cladoceran, *Daphnia magna*	-	Cadmium chloride	130	96 hr	EC50	5	1.893	-	Attar and Maly 1982
Cladoceran, *Daphnia magna*	-	Cadmium chloride	200	20 days	LC50	670	239.9	-	Canton and Slooff 1982

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Cladoceran, *Daphnia magna*	S, U	-	45	48 hr	LC50	118 (fed bacterial suspension)	131.3	-	Mount and Norberg 1984
Cladoceran, *Daphnia magna*	S, M	Cadmium chloride	55-79	48 hr	LC50	166 (High TOC)	123.3	-	Spehar and Carlson 1984a,b
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50	140	40.35	-	Lewis and Weber 1985
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	49.0	11.97	-	Hall et al. 1986
Cladoceran (<4 hr), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	164	216.8	-	Nebeker et al. 1986a
			41			99	121.1	-	
			71			101	70.71	-	
			74			120	80.56	-	
			76			65	42.47	-	
Cladoceran (<4 hr), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	16	21.15	-	Nebeker et al. 1986a
			74			146	98.01	-	
Cladoceran (1 d), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	307	405.8	-	Nebeker et al. 1986a
			71			135	94.52	-	
			74			200	134.3	-	
			76			45	29.40	-	
Cladoceran (2 d), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	131	173.2	-	Nebeker et al. 1986a
			71			18	12.60	-	
			74			38	25.51	-	
			76			21	13.72	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (5 d), *Daphnia magna*	S, M, T	Cadmium chloride	34	48 hr	LC50	24	35.52	-	Nebeker et al. 1986b
Cladoceran (5 d), *Daphnia magna*	R, M, T	Cadmium chloride	225	21 days	LOEC reproduction	2.3	0.755	-	Enserink et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	48 hr	LC50	48 (fed)	-	-	Domal-Kwiatkowska et al. 1994
Cladoceran (14 days), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50	80	23.06	-	Allen et al. 1995
Cladoceran (egg), *Daphnia magna*	S, M, T	Cadmium chloride	150	46 hr	Profound effect on egg development	>1,000	>327.3	-	Bodar et al. 1989
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	240	48 hr	LC50	1,880	381.6	-	Khangarot and Ray 1989a
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	250	48 hr (fed)	LC50 (small neonates)	98	19.08	-	Enserink et al. 1990
					LC50 (large neonates)	294	57.25	-	
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50 (20°C) (fed)	38	10.95	-	Lewis and Horning 1991
					LC50 (26°C) (fed)	9	2.594	-	
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	10	48 hr	LC50	37.9	194.6	-	Hickey and Vickers 1992

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	S, U	Cadmium acetate	-	24 hr	EC50	980	-	-	Sorvari and Sillanpaa 1996
Cladoceran (<24 hr), *Daphnia magna*	R, M, T	Cadmium chloride	-	24 hr	EC50	1,900	-	-	Kuhn et al. 1989
				24 days	NOEC reproduction	0.6	-	-	
Cladoceran, *Daphnia magna*	R, U	Cadmium sulfate	90	10 days	NOEC reproduction	2.5	1.617	-	Winner 1988
Cladoceran, *Daphnia magna*	R, U	Cadmium sulfate	100	25 days	NOEC (20°C) reproduction	2.25	1.346	-	Winner and Whitford 1987
					NOEC (25°C) reproduction	0.75	0.4488	-	
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	57	140 days	Reduced reproduction	1	0.9075	-	Bertram and Hart 1979
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	110	48 hr	LC50 (fed)	115 (104-127)	51.59	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	106	58 days	MATC	7.1 (5-10)	4.069	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S, U	-	45	48 hr	LC50	68 (fed bacterial suspension)	75.69	-	Mount and Norberg 1984
Cladoceran, *Daphnia pulex*	-	Cadmium sulfate	100	72 hr	LC50 (fed)	85.8 (80-92)	42.41	-	Winner 1984

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	100	24.43	-	Hall et al. 1986
Cladoceran (adult), *Daphnia pulex*	S, U	Cadmium chloride	124-130	48 hr	LC50	87.9	34.08	-	Jindal and Verma 1990
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	80-90	48 hr	LC50	24	13.99	-	Lewis and Weber 1985
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	80-90	48 hr	LC50 (20°C) (fed) LC50 (26°C) (fed)	42 6	24.49 3.498	- -	Lewis and Horning 1991
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	80-90	21 days	NOEC reproduction	<0.003	<0.0020	-	Roux et al. 1993
Cladoceran (<24 hr), *Daphnia pulex*	R, M, T	Cadmium chloride	58 115 230	21 days 21 days 21 days	NOEC survival NOEC brood size NOEC brood size	3.8 7.5 7.5	3.404 4.046 2.421	- - -	Winner 1986
Cladoceran, *Moina macrocopa*	-	Cadmium chloride	80-84	20 days	Reduced survival	0.2	0.1386	-	Hatakeyama and Yasuno 1981b
Cladoceran, *Moina macrocopa*	R, M, T	Cadmium chloride	-	240 hr	Reduced survival	10	-	-	Wong and Wong 1990
Cladoceran, *Moina macrocopa*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	320	427.6	-	Sharma and Selvaraj 1994
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	55-79	48 hr	LC50	123 (high TOC)	91.35	-	Spehar and Carlson 1984a,b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Simocephalus vetulus*	S, U	-	45	48 hr	LC50	24 (fed bacterial suspension)	26.71	-	Mount and Norberg 1984
Cladoceran, *Simocephalus vetulus*	S, M	Cadmium chloride	55-79	48 hr	LC50	89.3 (high TOC)	66.32	-	Spehar and Carlson 1984a,b
Copepod, *Acanthocyclops viridis*	-	Cadmium sulfate	-	72 hr	LC50	0.5	-	-	Braginskly and Shcherban 1978
Copepod, *Eucyclops agilis*	-	Cadmium chloride	11.1	52 wk	Population reduction	5	15.25	-	Giesy et al. 1979
Copepod, *Mesocyclops hyalinus*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	870	1,162	-	Sharma and Selvaraj 1994
Copepod, *Heliodinptomus vidus*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	150	200.4	-	Sharma and Selvaraj 1994
Copepod, *Tropocyclops prasinus mexicanus*	S, U	Cadmium chloride	10	48 hr	LC50	149	765.2	-	Lalande and Pinel-Alloul 1986
Copepod, *Stenocypris malcolmsoni*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	11,500	15,365	-	Sharma and Selvaraj 1994
Amphipod, *Diporeia* sp.	S, M, T	Cadmium chloride	-	96 hr	LC50 (4°C) LC50 (10°C) LC50 (15°C)	800 280 60	- - -	- - -	Gossiaux et al. 1992

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	55-79	96 hr	LC50	54.4	40.40	-	Spehar and Carlson 1984a,b
Amphipod, *Hyalella azteca*	S, M	Cadmium chloride	217-301	24 hr	LC50	140	26.30	-	McNulty et al. 1999
Amphipod, *Hyalella azteca*	S, M	Cadmium chloride	55-79	96 hr	LC50	285 (high TOC)	211.7	-	Spehar and Carlson 1984a,b
Amphipod, *Hyalella azteca*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	12 (pH-5.0) 16 (pH=5.5) 33 (pH=6.0)	40.00 53.33 110.0	- - -	Mackie 1989
Amphipod (0-2 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈13	≈7.15	-	Collyard et al. 1994
Amphipod (2-4 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈7.5	≈4.13	-	Collyard et al. 1994
Amphipod (4-6 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈9.5	≈5.23	-	Collyard et al. 1994
Amphipod (10-12 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈7	≈3.85	-	Collyard et al. 1994
Amphipod (16-18 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈11.5	≈6.33	-	Collyard et al. 1994
Amphipod (24-26 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈14	≈7.70	-	Collyard et al. 1994

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Amphipod, *Hyalella azteca*	R, M, T	Cadmium nitrate	130	6 wk	EC50	0.53	0.2006	-	Borgmann et al. 1991
Amphipod, *Hyalella azteca*	F, M, T	Cadmium chloride	44-47	10 days	LC50	2.8	3.003	-	Phipps et al. 1995
Amphipod, *Hyalella azteca*	S, M, T	Cadmium nitrate	280-300	96 hr	LC50 (fed)	230	38.52	-	Schubauer-Berigan et al. 1993
Crayfish, *Cambarus latimanus*	-	Cadmium chloride	11.1	5 mo	Significant mortality	5	15.25	-	Thorp et al. 1979
Crayfish, *Orconectes immunis*	S, M, T	Cadmium chloride	50.3	96 hr	LC50	>10,000	>9,939	-	Thorp and Gloss 1986
Anostracan crustacean, *Brachionus calyciflorus*	S, U	Cadmium sulfate	250	24 hr	EC50	120	23.37	-	Crisinel et al. 1994
Anostracan crustacean, *Streptocephalus rubricaudatus*	S, U	Cadmium sulfate	250	24 hr	EC50	250	48.68	-	Crisinel et al. 1994
Anostracan crustacean, *Thamnocephalus platyurus*	S, U	Cadmium chloride	80-100	24 hr	LC50	400	220.1	-	Centeno et al. 1995
Mayfly, *Cloeon dipterum*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	70,600	-	-	Braginskly and Shcherban 1978
					(15°C)	28,600	-	-	
					(25°C)	6,990	-	-	
					(30°C)	930	-	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Mayfly, *Cloeon dipterum*	-	Cadmium nitrate	-	48 hr	LC50	56,000	-	-	Slooff et al. 1983
Damselfly, *Enallagma* sp.	S, M, T	Cadmium chloride	15.3	96 hr	LC50	7,050 (pH=3.5)	23,497	-	Mackie 1989
						8,660 (pH=4.0)	28,863	-	
						10,660 (pH=4.5)	35,528	-	
Mayfly, *Ephemerella* sp.	-	Cadmium chloride	44-48	28 days	LC50	<3.0	<3.191	-	Spehar et al. 1978
Mayfly, *Paraleptophlebia praepedita*	S, M	Cadmium chloride	55-77	96 hr	LC50	449	338.6	-	Spehar and Carlson 1984a,b
Mayfly, *Hexagenia rigida*	-	Cadmium nitrate	79.1	96 hr	LC50	≥1,000	≥627.3	-	Leonhard et al. 1980
Mosquito, *Aedes aegypti*	-	Cadmium nitrate	-	48 hr	LC50	4,000	-	-	Slooff et al. 1983
Mosquito, *Culex pipiens*	-	Cadmium nitrate	-	48 hr	LC50	765	-	-	Slooff et al. 1983
Midge, *Chironomus tentans*	S, U	Cadmium chloride	25	48 hr	LC50	8,050	16,286	-	Khangarot and Ray 1989b
Midge (1st instar), *Chironomus riparius*	S, M, T	-	100	1 hr	Reduced emergence	2,100	1,038	-	McCahon and Pascoe 1991
				10 hr	Reduced emergence	210	103.8	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Midge (4th instar), *Chironomus riparius*	S, M, T	-	100	1 hr	Reduced emergence	2,000	988.6	-	McCahon and Pascoe 1991
				10 hr	Reduced emergence	200	98.86	-	
Midge (1st instar), *Chironomus riparius*	R, M, T	-	98	17 days	LOEC survival, development and growth	150	91.11	-	Pascoe et al. 1989
Midge (2nd instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	13,000	6,115	-	Williams et al. 1986
Midge (3rd instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	22,000	10,348	-	Williams et al. 1986
Midge (4th instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	54,000	25,400	-	Williams et al. 1986
Midge, *Chironomus riparius*	S, U	Cadmium chloride	98	120 hr	LOEC (egg viability)	30,000	18,222	-	Williams et al. 1987
				10 days	LOEC (number of eggs ovipositioned)	100,000	60,739	-	
Midge, *Tanytarsus dissimilis*	-	Cadmium chloride	47	10 days	LC50	3.8	3.978	-	Anderson et al. 1980
Pink salmon (newly hatched alevin), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	3,600	2,148	-	Servizi and Martens 1978
Pink salmon (alevin), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	3,160	1,885	-	Servizi and Martens 1978

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Pink salmon (fry), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	2,700	1,611	-	Servizi and Martens 1978
Coho salmon (juvenile), *Oncorhynchus kisutch*	-	Cadmium chloride	22	217 hr	LC50	2.0	4.608	-	Chapman and Stevens 1978
Coho salmon (adult), *Oncorhynchus kisutch*	-	Cadmium chloride	22	215 hr	LC50	3.7	8.524	-	Chapman and Stevens 1978
Coho salmon (alevin), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	96 hr	LC50	6.0	7.341	-	Buhl and Hamilton 1991
Sockeye salmon (newly hatched alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	4,500	2,685	-	Servizi and Martens 1978
Sockeye salmon (alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	1,000	596.6	-	Servizi and Martens 1978
Sockeye salmon (alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	500	298.3	-	Servizi and Martens 1978
Sockeye salmon (fry), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	30	17.90	-	Servizi and Martens 1978
Sockeye salmon (fry), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	8	4.773	-	Servizi and Martens 1978
Sockeye salmon (smolt), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	360	214.8	-	Servizi and Martens 1978

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	21.6 (18-26)	47.57	-	Chapman 1978
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.2	2.643	-	Chapman 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.3	2.863	-	Chapman 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.5	3.303	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium stearate	-	96 hr	LC50	6.0	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium acetate	-	96 hr	LC50	6.2	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	112	80 min	Significant avoidance	52	22.91	-	Black and Birge 1980
Rainbow trout, *Oncorhynchus mykiss*	-	-	112	18 mo	Reduced survival	0.2	0.1100	-	Birge et al. 1981
Rainbow trout, (embryo, larva) *Oncorhynchus mykiss*	-	Cadmium chloride	104	28 days	EC50 (death and deformity)	140	81.37	-	Birge 1978; Birge et al. 1980

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	-	-	240 hr	LC50	7 5	-	-	Kumada et al. 1973
Rainbow trout (adult), *Oncorhynchus mykiss*	-	Cadmium chloride	54	408 hr	LC50	5.2	4.912	-	Chapman and Stevens 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	-	Cadmium chloride	23	186 hr	LC10	>6	>13.21	-	Chapman 1978
Rainbow trout (swim-up), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	1.0	2.202	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	0.7	1.541	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	0.8	1.762	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium sulfate	326	96 hr	LC20	20	2.973	-	Davies 1976
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium stearate	-	10 wk	BCF = 27 BCF = 40	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium acetate	-	10 wk	BCF = 63	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	125	10 days	LC50 (18°C) (12°C) (6°C)	17.3 (10-30) 30 17.3 (10-30)	6.816 11.82 6.816	- - -	Roch and Maly 1979

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium sulfate	240	234 days	Increased gill diffusion	2	0.6256	-	Hughes et al. 1979
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	320	4 mo	Physiological effects	10	2.528	-	Arillo et al. 1982, 1984
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	98.6	47 days	Reduced growth and survival	100	60.47	-	Woodworth and Pascoe 1982
Rainbow trout, (embryo, larva) *Oncorhynchus mykiss*	-	Cadmium sulfate	100	62 days	Reduced Survival	<5	<2.992	-	Dave et al. 1981
Rainbow trout (larva), *Oncorhynchus mykiss*	-	Cadmium chloride	89-107	7 days	LC50	700	353.2	-	Birge et al. 1983
Rainbow trout (larva), *Oncorhynchus mykiss*	-	Cadmium chloride	89-107	7 days	LC50 after 24 days acclimated to 5.9 µg/L	1,590	802.2	-	Birge et al. 1983
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium nitrate	-	48 hr	LC50	55	-	-	Slooff et al. 1983
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	55-79	96 hr	LC50	10.2 (high TOC)	7.575	-	Spehar and Carlson 1984a,b
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	11 days	LC50 (10°C)	16.0	9.676	-	Majewski and Giles 1984
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	8 days	LC50 (15°C)	16.6	10.04	-	Majewski and Giles 1984

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	178 days	Physiological effects	4.8 (3.6-6.4)	3.327	-	Majewski and Giles 1984
Rainbow trout, (egg-0 hr) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	13,000	13,000	-	Van Leeuwen et al. 1985a
Rainbow trout, (egg-24 hr) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	13,000	13,000	-	Van Leeuwen et al. 1985a
Rainbow trout, (eyed egg-14 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	7,500	7,500	-	Van Leeuwen et al. 1985a
Rainbow trout, (eyed egg-28 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	9,200	9,200	-	Van Leeuwen et al. 1985a
Rainbow trout, (sac fry-42 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	30	30.00	-	Van Leeuwen et al. 1985a
Rainbow trout, (early fry-77 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	10	10.00	-	Van Leeuwen et al. 1985a
Rainbow trout, *Oncorhynchus mykiss*	R, M, D	Cadmium chloride	63 300	96 hr 96 hr	LC50 (fed) LC50 (fed)	1,300 2,600	1,028 420.6	- -	Pascoe et al. 1986
Rainbow trout, (5 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	>100,000	>56,483	-	Shazili and Pascoe 1986

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Rainbow trout, (10 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	3,300	1,864	-	Shazili and Pascoe 1986
Rainbow trout, (15 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	7,200	4,067	-	Shazili and Pascoe 1986
Rainbow trout, (22 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	8,000	4,519	-	Shazili and Pascoe 1986
Rainbow trout, (29 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	12,500	7,060	-	Shazili and Pascoe 1986
Rainbow trout, (36 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	16,500	9,320	-	Shazili and Pascoe 1986
Rainbow trout, (alevin, 2 d post hatch) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	5,800	3,276	-	Shazili and Pascoe 1986
Rainbow trout, (alevin, 7 d post hatch) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	8,300	4,688	-	Shazili and Pascoe 1986
Rainbow trout (alevin), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	96 hr	LC50	37.9	46.37	-	Buhl and Hamilton 1991

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	9.2	96 hr	LC50	28 (pH=4.7) 0.7 (pH=5.7)	156.5 3.913	- -	Cusimano et al. 1986
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	50	96 hr	LC50	2.7	2.700	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	200	96 hr	LC50	3.2	0.7818	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	400	96 hr	LC50	7.6	0.9178	-	Davies et al. 1993
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	55-79	96 hr	LC50	15.1	11.21	-	Spehar and Carlson 1984a,b
Atlantic salmon, *Salmo salar*	-	Cadmium chloride	13	70 days	Reduced growth	2	5.426	-	Peterson et al. 1983
Atlantic salmon (alevin), *Salmo salar*	R, M, T	Cadmium chloride	28	92 days	Net water uptake inhibited	0.78	1.199	-	Rombough and Garside 1984
Brook trout, *Salvelinus fontinalis*	-	Cadmium chloride	10	21 days	Testicular damage	10	32.95	-	Sangalang and O'Halloran 1972, 1973
Brook trout (8 months), *Salvelinus fontinalis*	R, M, T	-	20	10 days	NOEL survival	8	20.31	-	Jop et al. 1995
Lake trout, *Salvelinus namaycush*	F, M, T	Cadmium chloride	90	8-9 mo	Decreased thyroid follicle epithelial cell height	5	3.235	-	Scherer et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Arctic grayling (alevin), *Thymallus arcticus*	S, U	Cadmium chloride	41	96 hr	LC50	6.1 (1-d acclimation)	7.464	-	Buhl and Hamilton 1991
Arctic grayling (juvenile), *Thymallus arcticus*	S, U	Cadmium chloride	41	96 hr	LC50	4.0 (low D.O.)	4.894	-	Buhl and Hamilton 1991
Goldfish (embryo, larva), *Carassius auratus*	-	Cadmium chloride	195	7 days	EC50 (death and deformity)	170	43.62	-	Birge 1978
Goldfish, *Carassius auratus*	-	-	-	50 days	Reduced plasma sodium	44.5	-	-	McCarty and Houston 1976
Common carp (embryo), *Cyprinus carpio*	-	Cadmium sulfate	360	-	EC50 (hatch)	2,094	281.5	-	Kapur and Yadav 1982
Common carp (fry), *Cyprinus carpio*	S, U	-	100	96 hr	LC50	4,260	2,106	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U,	-	100	96 hr	LC50	17,050	8,428	-	Suresh et al. 1993a
Common carp (embryo, larva), *Cyprinus carpio*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	139	67.61	-	Birge et al. 1985
Common shiner (0.75-3.5 mg), *Notropis cornutus*	R, M, D	Cadmium chloride	48	7 days	67% reduced growth	200	208.5	-	Borgmann and Ralph 1986

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	63	96 hr	LC50	80.8	63.88	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	55	96 hr	LC50	40.9	37.12	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	59	96 hr	LC50	64.8	54.77	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	66	96 hr	LC50	135	101.8	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	65	96 hr	LC50	120	91.91	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	74	96 hr	LC50	86.3	57.93	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	79	96 hr	LC50	86.6	54.40	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	62	96 hr	LC50	114	91.61	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	63	96 hr	LC50	80.8	63.88	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium nitrate	-	48 hr	LC50	2,200	-	-	Slooff et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	103	6.8 hr	LT50	6,000	2,878	-	Birge et al. 1983

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	254-271	3.7 hr	LT50	16,000	2,965	-	Birge et al. 1983
Fathead minnow (larva), *Pimephales promelas*	-	Cadmium chloride	89-107	7 days	LC50	200	100.9	-	Birge et al. 1983
Fathead minnow (larva), *Pimephales promelas*	-	Cadmium chloride	89-107	7 days	LC50 after 4 days acclimated to 5.6 µg/L	540	272.5	-	Birge et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	-	4 days	Histological effects	12,000	-	-	Stromberg et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium nitrate	209	48 hr	LC50	802	187.4	-	Slooff et al. 1983
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	55-79	96 hr	LC50	3,390	2,518	-	Spehar and Carlson 1984a,b
Fathead minnow, *Pimephales promelas*	F, M	Cadmium chloride	55-79	96 hr	LC50	1,830	1,359	-	Spehar and Carlson 1984a,b
Fathead minnow (1-7 d), *Pimephales promelas*	R, M, T	Cadmium chloride	70-90	48 hr	LC50	35.4	21.95	-	Diamond et al. 1997
Fathead minnow (embryo, larva), *Pimephales promelas*	F, M, T	Cadmium chloride	101.6	8 days	LC50	125 (20.1°C)	60.80	-	Birge et al. 1985
						84 (22.8°C)	40.86	-	
						76 (25.7°C)	36.96	-	
						87 (27.9°C)	42.31	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Fathead minnow (embryo, larva), *Pimephales promelas*	R, M, T	Cadmium chloride	101.6	8 days	LC50 NOEC	41 12	19.94 5.836	- -	Birge et al. 1985
Fathead minnow (embryo, larva), *Pimephales promelas*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	107	52.04	-	Birge et al. 1985
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	96 hr	LC50	13.2	15.03	-	Spehar and Fiandt 1986
Fathead minnow (14-30 d), *Pimephales promelas*	S, U	Cadmium chloride	200	96 hr	LC50	90	21.99	-	Hall et al. 1986
White sucker (larva), *Catostomus commersoni*	R, M, D	Cadmium chloride	48	7 days	46% reduced growth	36	37.53	-	Borgmann and Ralph 1986
Brown bullhead, *Ictalurus nebulosus*	-	Cadmium chloride	-	2 hr	Affected gills and kidney	61,300	-	-	Blickens 1978; Garofano 1979
Channel catfish, *Ictalurus punctatus*	-	Cadmium chloride	-	-	Increased albinism	0.5	-	-	Westerman and Birge 1978
Channel catfish, *Ictalurus punctatus*	-	Cadmium chloride	-	-	BCF = 4.0-6.7	-	-	-	Birge et al. 1979
Channel catfish, *Ictalurus punctatus*	S, M	Cadmium chloride	55-79	96 hr	LC50	7,940	5,897	-	Spehar and Carlson 1984a,b
Walking catfish, *Clarias batrachus*	S, U	Cadmium chloride	-	14 days	60% mortality	8,993	-	-	Jana and Sahana 1989

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total μg/L)[b]	Result Adjusted to TH=50 (Total μg/L)	Result Adjusted to TH=50 (Dissolved μg/L)	Reference
					FRESHWATER SPECIES				
Mummichog, *Fundulus heteroclitus*	S, U	Cadmium chloride	5	96 hr	TL50	12.2	126.8	-	Gill and Epple 1992
Mosquitofish, *Gambusia affinis*	-	Cadmium chloride	-	8 wk	BCF = 6,100 at 0.02 μg/L & 1.13 ppm added to food	-	-	-	Williams and Giesy 1978
Mosquitofish, *Gambusia affinis*	-	Cadmium chloride	29	8 wk	BCF = 1,430 at 10 μg/L & 1.13 ppm added to food	-	-	-	Williams and Giesy 1978
Mosquitofish, *Gambusia affinis*	R, M, T	Cadmium sulfate	45	48 hr	LC50	7,260	8,081	-	Chagnon and Guttman 1989
Guppy, *Poecilla reticulata*	-	Cadmium nitrate	209	48 hr	LC50	41,900	9,789	-	Slooff et al. 1983
Guppy, *Lebistes reticulatus*	S, U	Cadmium chloride	140-190	96 hr	LC50 (fry) LC50 (male) LC50 (female)	2,500 12,750 16,000	742.7 3,788 4,753	- - -	Gadkari and Marathe 1983
Threespine stickleback, *Gasterosteus aculeatus*	F, M, T	Cadmium sulfate	299	18 days	Kidney cell tissue breakdown	6,000	1,595	-	Oronsaye 1989
Bluegill, *Lepomis macrochirus*	-	Cadmium chloride	112	80 min	Significant avoidance	>41.1	>18.10	-	Black and Birge 1980
Bluegill, *Lepomis macrochirus*	-	Cadmium chloride	340-360	3 days	Increased cough rate	50	6.916	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	55-79	96 hr	LC50	8,810	6,543	-	Spehar and Carlson 1984a,b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total μg/L)[b]	Result Adjusted to TH=50 (Total μg/L)	Result Adjusted to TH=50 (Dissolved μg/L)	Reference
					FRESHWATER SPECIES				
Bluegill (juvenile), *Lepomis macrochirus*	F, M, T	Cadmium chloride	134	32 days	NOEC growth	>32.3	>15.56	-	Cope et al. 1994
Bluegill (31.1 ± 1.3 mm), *Lepomis macrochirus*	F, M, T	Cadmium chloride	174	22 days	LOEC prey attack rate	37.3	14.81	-	Bryan et al. 1995
Largemouth bass, *Micropterus salmoides*	-	Cadmium chloride	112	80 min	Significant avoidance	8.83	3.890	-	Black and Birge 1980
Largemouth bass, (embryo, larva) *Micropterus salmoides*	-	Cadmium chloride	99	8 days	EC50 (death and deformity)	1,640	818.9	-	Birge et al. 1978
Largemouth bass, *Micropterus salmoides*	-	-	-	24 hr	Affected opercular activity	150	-	-	Morgan 1979
Largemouth bass, (embryo, larva), *Micropterus salmoides*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	244	118.7	-	Birge et al. 1985
Orangethroat darter (embryo), *Etheostoma spectabile*	R, M, T	Cadmium chloride	180	96 hr	LC50	>500	>136.0	-	Sharp and Kaszubski 1989
Tilapia (larva <1 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	205	-	-	Hwang et al. 1995
Tilapia (larva, 1 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	83	-	-	Hwang et al. 1995

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Tilapia (larva, 2 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	33	-	-	Hwang et al. 1995
Tilapia (larva, 3 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	22	-	-	Hwang et al. 1995
Tilapia (larva, 7 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	29	-	-	Hwang et al. 1995
Tilapia (72 hr), *Oreochromis mossambica*	S, U	Cadmium chloride	28	96 hr	LC50	21.4	38.58	-	Chang et al. 1998
Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis*	-	Cadmium chloride	195	7 days	EC50 (death and deformity)	40	10.03	-	Birge 1978
African clawed frog, *Xenopus laevis*	-	Cadmium nitrate	209	48 hr	LC50	11,700	2,733	-	Slooff and Baerselman 1980; Slooff et al. 1983
African clawed frog, *Xenopus laevis*	-	-	170	48 hr	LC50	3,200	922.3	-	Canton and Slooff 1982
African clawed frog, *Xenopus laevis*	-	-	170	100 days	Inhibited development	650	262.5	-	Canton and Slooff 1982
African clawed frog, *Xenopus laevis*	S, U	Cadmium chloride	-	24 hr	LC50 (stage 40)	1,000	-	-	Herkovits et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
African clawed frog, *Xenopus laevis*	S, U	Cadmium chloride	-	72 hr	LC50 (stage 40) LC50 (stage 47)	0.2 1.6	- -	- -	Herkovits et al. 1998
Northwestern salamander (3 mo larva), *Ambystoma gracile*	F, M, T	Cadmium chloride	45	10 days	LOAEC (limb regeneration)	44.6	49.64	-	Nebeker et al. 1994
Northwestern salamander, *Ambystoma gracile*	F, M, T	Cadmium chloride	45	10 days	LOAEL growth	227	252.7	-	Nebeker et al. 1995
Marbled salamander (embryo, larva), *Ambystoma opacum*	-	Cadmium chloride	99	8 days	EC50 (death and deformity)	150	74.90	-	Birge et al. 1978
Lake study, Periphyton and amphipods	S, M, T	Cadmium chloride	-	120 days	BCF = 64,000 (periphyton) BCF = 24,000 (*Hyalella azteca*)	- -	- -	- -	Stephenson and Turner 1993
Stream microcosm	F, M, T	Cadmium nitrate	-	21 days	No effect on periphyton structure, but adverse effect on invertebrate grazers and collectors	22	-	-	Selby et al. 1985

[a] S= static, R= renewal, F= flow-through, M= measured, U= unmeasured, T= total measured concentration, D=dissolved metal concentration measured.
[b] Results are expressed as cadmium, not as the chemical.

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Bacterium (Microtox®), *Vibrio fischeri*	S, U	Cadmium nitrate	35	22 hr	EC50	214	-	-	Radix et al. 1999
Natural phytoplankton population	-	Cadmium chloride	-	4 days	Reduced biomass	112	-	-	Hollibaugh et al. 1980
Green alga, *Acetabularia acetabulum*	S, U	Cadmium chloride	-	3 wk	Morphological deformities	100	-	-	Karez et al. 1989
					Decreased cell elongation	1	-	-	
Phytoflagellate, *Olisthodiscus luteus*	S, M, T	Cadmium chloride	-	192 hr	27% biovolume reduction	500	-	-	Fernandez-Leborans and Novillo 1996
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	2 days	NOEC sexual reproduction	>100	-	-	Thursby and Steele 1986
Alga, *Tetraselmis gracilis*	S, U	-	-	96 hr	LC50	1,800	-	-	Okamoto et al. 1996
Diatom, *Minutocellus polymorphus*	S, U	Cadmium chloride	-	48 hr	EC50	66	-	-	Walsh et al. 1988
Diatom, *Skeletonema costatum*	S, U	-	-	10 days	EC50 growth	450	-	-	Govindarajan et al. 1993
Diatom, *Skeletonema costatum*	S, U	Cadmium chloride	-	72 hr	EC50	144	-	-	Walsh et al. 1988

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Hydroid, *Campanularia flexuosa*	-	-	-	-	Enzyme inhibition	40-75	-	-	Moore and Stebbing 1976
Hydroid, *Campanularia flexuosa*	-	-	-	11 days	Growth rate	110-280	-	-	Stebbing 1976
Rotifer, *Brachionus plicatilis*	S, U	Cadmium chloride	15	24 hr	LC50	54,900	-	-	Snell and Personne 1989b
Rotifer, *Brachionus plicatilis*	S, U	Cadmium chloride	30	24 hr	LC50	56,800	-	-	Snell and Personne 1989b
Rotifer, *Brachionus plicatilis*	S, U	Cadmium nitrate	15	24 hr	LC50	>39,000	-	-	Snell et al. 1991b
Polychaete worm, *Neanthes arenaceodentata*	-	Cadmium chloride	-	28 days	LC50	3,000	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	-	Cadmium chloride	-	28 days	LC50	630	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	-	Cadmium chloride	-	28 days	LC50	700	-	-	Reish et al. 1976
Polychaete worm, *Nereis virens*	R, M	Cadmium chloride	-	144 hr	LC50	170	-	-	McLeese and Ray 1986
Clam, *Macoma balthica*	R, M	Cadmium chloride	-	144 hr	LC50	1,710	-	-	McLeese and Ray 1986
Blue mussel, *Mytilus edulis*	-	Cadmium EDTA	-	28 days	BCF = 252	-	-	-	George and Coombs 1977

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Blue mussel, *Mytilus edulis*	-	Cadmium alginate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium humate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium pectate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium chloride	-	21 days	BCF = 710	-	-	-	Janssen and Scholz 1979
Blue mussel, *Mytilus edulis*	F, M, T	Cadmium chloride	28	2 wk	LT50 = 9.5 days (anoxic conditions)	47	-	-	Veldhuizen-Tsoerkan et al. 1991
Bay scallop, *Argopecten irradians*	-	Cadmium chloride	-	42 days	EC50 (growth reduction)	78	-	-	Pesch and Stewart 1980
Bay scallop, *Argopecten irradians*	-	Cadmium chloride	-	21 days	BCF = 168	-	-	-	Eisler et al. 1972
Eastern oyster, *Crassostrea virginica*	-	Cadmium iodide	-	40 days	BCF = 677	-	-	-	Kerfoot and Jacobs 1976
Eastern oyster, *Crassostrea virginica*	-	Cadmium chloride	-	21 days	BCF = 149	-	-	-	Eisler et al. 1972
Eastern oyster, *Crassostrea virginica*	-	Cadmium chloride	-	2 days	Reduction in embryonic development	15	-	-	Zaroogian and Morrison 1981

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	6 days	50% reduction in settlement	20-25	-	-	Watling 1983b
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	14 days	Growth reduction	10	-	-	Watling 1983b
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	23 days	LC50	50	-	-	Watling 1983b
Soft-shell clam, *Mya arenaria*	-	Cadmium chloride	-	7 days	LC50	150	-	-	Eisler 1977
Soft-shell clam, *Mya arenaria*	-	Cadmium chloride	-	7 days	LC50	700	-	-	Eisler and Hennekey 1977
Copepod (nauplius), *Eurytemora affinis*	-	Cadmium chloride	-	1 day	Reduction in swimming speed	130	-	-	Sullivan et al. 1983
Copepod (nauplius), *Eurytemora affinis*	-	Cadmium chloride	-	2 days	Reduction in development rate	116	-	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	S, M, T	Cadmium chloride	5 15	96 hr 96 hr	LC50 (fed) LC50 (fed)	51.6 213	- -	- -	Hall et al. 1995
Copepod, *Tisbe holothurlae*	-	Cadmium chloride	-	48 hr	LC50	970	-	-	Moraitou-Apostolopoulou and Verriopoulos 1982
Mysid, *Americamysis bahia*	-	-	15-23	17 days	LC50	11	-	-	Nimmo et al. 1977a

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Mysid, *Americamysis bahia*	-	Cadmium chloride	30	16 days	LC50	28	-	-	Gentile et al. 1982
Mysid, *Americamysis bahia*	-	Cadmium chloride	-	8 days	LC50	60	-	-	Gentile et al. 1982
Mysid, *Americamysis bahia*	F, M, T	-	13-29	28 days	NOEC survival, growth and reproduction	4-5	-	-	Voyer and McGovern 1991
Mysid, *Americamysis bahia*	S, M, T	-	12	24 hr	Reduced serum osmolality	3.62	-	-	De Lisle and Roberts 1994
Mysid (8 d), *Americamysis bahia*	R, U	Cadmium chloride	25	96 hr	NOEC survival and growth	5	-	-	Khan et al. 1992
				7 days	NOEC survival and growth	5	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	10	96 hr	LC50	47.0 (20°C)	-	-	Voyer and Modica 1990
						15.5 (25°C)	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	20	96 hr	LC50	73.0 (20°C)	-	-	Voyer and Modica 1990
						20.5 (25°C)	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	30	96 hr	LC50	85.0 (20°C)	-	-	Voyer and Modica 1990
						28.0 (25°C)	-	-	

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
SALTWATER SPECIES									
Mysid, *Mysidopsis bigelowi*	-	Cadmium chloride	-	8 days	LC50	70	-	-	Gentile et al. 1982
Mysid, *Mysidopsis bigelowi*	-	Cadmium chloride	-	28 days	LC50	18	-	-	Gentile et al. 1982
Isopod, *Idotea baltica*	-	Cadmium sulfate	3	5 days	LC50	10,000	-	-	Jones 1975
Isopod, *Idotea baltica*	-	Cadmium sulfate	21	3 days	LC50	10,000	-	-	Jones 1975
Isopod, *Idotea baltica*	-	Cadmium sulfate	14	1.5 days	LC50	10,000	-	-	Jones 1975
Sand shrimp, *Crangon septemspinosa*	R, M	Cadmium chloride	-	144 hr	LC50	1,160	-	-	McLeese and Ray 1986
Pink shrimp, *Pandalus montagui*	R, M	Cadmium chloride	-	144 hr	LC50	1,280	-	-	McLeese and Ray 1986
Pink shrimp, *Penaeus duorarum*	-	Cadmium chloride	-	30 days	LC50	720	-	-	Nimmo et al. 1977b
White shrimp, *Penaeus setiferus*	S, M, T	Cadmium chloride	11	96 hr	LC50	990	-	-	Vanegas et al. 1997
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	42 days	LC50	300	-	-	Pesch and Stewart 1980
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	5	21 days	LC25	50	-	-	Vernberg et al. 1977

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total μg/L)[b]	Result Adjusted to TH = 50 (Total μg/L)	Result (Dissolved μg/L)	Reference
				SALTWATER SPECIES					
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	10	21 days	LC10	50	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	20	21 days	LC5	50	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	10	6 days	LC75	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	15	6 days	LC50	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	30	6 days	LC25	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	21 days	BCF = 140	-	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	29 days	LC50	120	-	-	Nimmo et al. 1977b
American lobster, *Homarus americanus*	-	Cadmium chloride	-	21 days	BCF = 25	-	-	-	Eisler et al. 1972
American lobster, *Homarus americanus*	-	Cadmium chloride	-	30 days	Increase in ATPase activity	6	-	-	Tucker 1979
Hermit crab, *Pagurus longicarpus*	-	Cadmium chloride	-	7 days	25% mortality	270	-	-	Eisler and Hennekey 1977
Hermit crab, *Pagurus longicarpus*	-	Cadmium chloride	-	60 days	LC56	70	-	-	Pesch and Stewart 1980

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Yellow crab, *Cancer anthonyi*	R, U	Cadmium chloride	34	7 days	28% mortality	1,000	-	-	Macdonald et al. 1988
Rock crab, *Cancer irroratus*	-	Cadmium chloride	-	96 hr	Enzyme activity	1,000	-	-	Gould et al. 1976
Rock crab (larva), *Cancer irroratus*	-	Cadmium chloride	-	28 days	Delayed development	50	-	-	Johns and Miller 1982
Blue crab, *Callinectes sapidus*	-	Cadmium nitrate	10	7 days	LC50	50	-	-	Rosenberg and Costlow 1976
Blue crab, *Callinectes sapidus*	-	Cadmium nitrate	30	7 days	LC50	150	-	-	Rosenberg and Costlow 1976
Blue crab (juvenile), *Callinectes sapidus*	-	Cadmium chloride	1	4 days	LC50	320	-	-	Frank and Robertson 1979
Blue crab, *Callinectes sapidus*	R, M, T	Cadmium chloride	2.5 25	21 days 21 days	LC50 LC50	19 186	- -	- -	Guerin and Stickle 1995
Blue crab, *Callinectes sapidus*	S, M, T	Cadmium chloride	28	6-8 days	EC50 hatching	0.25	-	-	Lee et al. 1996
Mud crab (larva), *Eurypanopeus depressus*	-	Cadmium chloride	-	8 days	LC50	10	-	-	Mirkes et al. 1978
Mud crab (larva), *Eurypanopeus depressus*	-	Cadmium chloride	-	44 days	Delay in metamorphysis	10	-	-	Mirkes et al. 1978
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	10	11 days	LC80	50	-	-	Rosenberg and Costlow 1976

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	20	11 days	LC75	50	-	-	Rosenberg and Costlow 1976
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	30	11 days	LC40	50	-	-	Rosenberg and Costlow 1976
Fiddler crab, *Uca pugilator*	-	-	-	10 days	LC50	2,900	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	-	Cadmium chloride	-	-	Effect on respiration	1.0	-	-	Vernberg et al. 1974
Starfish, *Asterias forbesi*	-	Cadmium chloride	-	7 days	25% mortality	270	-	-	Eisler and Hennekey 1977
Sea urchin, *Arbacia punctulata*	S, U	Cadmium chloride	30	1 hr	EC50 (sperm cell)	38,000	-	-	Nacci et al. 1986
				4 hr	EC50 (embryo growth	13,900	-	-	
Green sea urchin, *Strongylocentrotus droebachiensis*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	26,000	-	-	Dinnel et al. 1989
Red sea urchin, *Strongylocentrotus franciscanus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	12,000	-	-	Dinnel et al. 1989
Purple sea urchin, *Strongylocentrotus purpuratus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	18,000	-	-	Dinnel et al. 1989

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Purple sea urchin, *Strongylocentrotus purpuratus*	S, U	Cadmium chloride	30	40 min	NOEC sperm-fertilization	>67	-	-	Bailey et al. 1995
Sand dollar, *Dendraster excentricus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	8,000	-	-	Dinnel et al. 1989
Sand dollar, *Dendraster excentricus*	S, U	Cadmium chloride	30	40 min	NOEC sperm-fertilization	>67	-	-	Bailey et al. 1995
Herring (larva), *Clupea harengus*	-	Cadmium chloride	-	-	100% embryonic survival	5,000	-	-	Westernhagen et al. 1979
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	<24 hr	17% reduction in volume	10,000	-	-	Alderdice et al. 1979a
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	96 hr	Decrease in capsule strength	1,000	-	-	Alderdice et al. 1979b
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	48 hr	Reduced osmolality of periviteline fluid	1,000	-	-	Alderdice et al. 1979c
Sheepshead minnow, *Cyprinodon variegatus*	R, M, T	Cadmium chloride	34-35	96 hr	LC50 (fed)	1,230	-	-	Hutchinson et al. 1994
				7 days	NOEC survival and growth	560	-	-	
Sheepshead minnow, *Cyprinodon variegatus*	S, M, T, D	Cadmium chloride	5	96 hr	LC50 (fed)	180	-	-	Hall et al. 1995
			15	96 hr	LC50 (fed)	312	-	-	
			25	96 hr	LC50 (fed)	496	-	-	

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Mummichog (adult), *Fundulus heteroclitus*	-	Cadmium chloride	20	48 hr	LC50	60,000	-	-	Middaugh and Dean 1977
Mummichog (adult), *Fundulus heteroclitus*	-	Cadmium chloride	30	48 hr	LC50	43,000	-	-	Middaugh and Dean 1977
Mummichog, *Fundulus heteroclitus*	-	Cadmium chloride	-	21 days	BCF = 48	-	-	-	Eisler et al. 1972
Mummichog (larva), *Fundulus heteroclitus*	-	Cadmium chloride	20	48 hr	LC50	32,000	-	-	Middaugh and Dean 1977
Mummichog (larva), *Fundulus heteroclitus*	-	Cadmium chloride	30	48 hr	LC50	7,800	-	-	Middaugh and Dean 1977
Mummichog (<23 d), *Fundulus heteroclitus*	S, M, T	Cadmium chloride	10	48 hr	LC50	44,400	-	-	Burton and Fisher 1990
Atlantic silverside (adult), *Menidia menidia*	-	Cadmium chloride	20	48 hr	LC50	13,000	-	-	Middaugh and Dean 1977
Atlantic silverside (adult), *Menidia menidia*	-	Cadmium chloride	30	48 hr	LC50	12,000	-	-	Middaugh and Dean 1977
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	12	19 days	LC50	<160	-	-	Voyer et al. 1979
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	20	19 days	LC50	540	-	-	Voyer et al. 1979

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	30	19 days	LC50	>970	-	-	Voyer et al. 1979
Atlantic silverside (larva), *Menidia menidia*	-	Cadmium chloride	20	48 hr	LC50	2,200	-	-	Middaugh and Dean 1977
Atlantic silverside (larva), *Menidia menidia*	-	Cadmium chloride	30	48 hr	LC50	1,600	-	-	Middaugh and Dean 1977
Striped bass (juvenile), *Morone saxatilis*	-	Cadmium chloride	-	90 days	Significant decrease in enzyme activity	5	-	-	Dawson et al. 1977
Striped bass (juvenile), *Morone saxatilis*	-	Cadmium chloride	-	30 days	Significant decrease in oxygen consumption	0.5-5.0	-	-	Dawson et al. 1977
Spot (larva), *Leiostomus xanthurus*	-	Cadmium chloride	-	9 days	Incipient LC50	200	-	-	Middaugh and Dean 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	60 days	37.5% mortality	100	-	-	MacInnes et al. 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	30 days	Depressed gill tissue oxygen consumption	50	-	-	MacInnes et al. 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	96 hr	Decreased enzyme activity	3,000	-	-	Gould and Karolus 1974

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	8 days	50% viable hatch	300	-	-	Voyer et al. 1977
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	60 days	Increased gill tissue respiration	5	-	-	Calabrese et al. 1975
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	17 days	Reduction of viable hatch	586	-	-	Voyer et al. 1982

[a] S= static, R= renewal, F= flow-through, M= measured, U= unmeasured, T= total measured concentration, D=dissolved metal concentration measured.
[b] Results are expressed as cadmium, not as the chemical.

REFERENCES

Abbasi, S.A. and R. Soni. 1986. An examination of environmentally safe levels of zinc (II), cadmium (II) and lead (II) with reference to impact on channelfish *Nuria denricus*. Environ. Pollut. (Series A) 40(1): 37-51.

Abbasi, S.A. and R. Soni. 1989. Relative toxicity of seven heavy metals with respect to impact towards larvae of amphibian *Rana tigrina*. Intern. J. Environ. Stud. 35: 121-122.

Abel, P.D. and S.M. Garner. 1986. Comparisons of median survival times and median lethal exposure times for *Gammarus pulex* exposed to cadmium, permethrin and cyanide. Water Res. 20(5): 579-582.

Abel, P.D. and S.E. Papoutsoglou. 1986. Lethal toxicity of cadmium to *Cyprinus carpio* and *Tilapia aurea*. Bull. Environ. Contam. Toxicol. 37: 382-386.

Abel, T. and F. Barlocher. 1988. Uptake of cadmium by *Gammarus fossarum* (Amphipoda) from food and water. J. Appl. Ecol. 25: 223-231.

Ahsanullah, M. 1976. Acute toxicity of cadmium and zinc to seven invertebrate species from Western Port, Victoria. Aust. J. Mar. Freshwater Res. 27: 187.

Ahsanullah, M. and A.R. Williams. 1991. Sublethal effects and bioaccumulation of cadmium, chromium, copper and zinc in the marine amphipod *Allorchestes compressa*. Mar. Biol. 108: 59-65.

Ahsanullah, M.D., et al. 1981. Toxicity of zinc, cadmium, and copper to the shrimp *Callianassa australiensis*. I. Effects of individual metals. Mar. Biol. 64: 299.

Al-atia, G.R. 1978. The uptake and toxicity of cadmium in *Amoeba proteus*. J. Protozool. 25: 5B.

Al-atia, G.R. 1980. Toxicity of cadmium to *Amoeba proteus*: a biochemical approach. J. Protozool. 27: 128.

Alderdice, D.F., et al. 1979a. Influence of salinity and cadmium on the volume of Pacific herring eggs. Helgol. Wiss. Meeresunters. 32:163.

Alderdice, D.F., et al. 1979b. Influence of salinity and cadmium on capsule strength in Pacific herring eggs. Helgol. Wiss. Meeresunters. 32: 149.

Alderdice, D.F., et al. 1979c. Osmotic responses of eggs and larvae of the Pacific herring to salinity and cadmium. Helgol. Wiss. Meeresunters. 32: 508.

Allen, P. 1994. Accumulation profiles of lead and the influence of cadmium and mercury in *Oreochromis aureus* (Steindachner) during chronic exposure. Toxicol. Environ. Chem. 44: 101-112.

Allen, P. 1995a. Soft-tissue accumulation of lead in the blue tilapia, *Oreochromis aureus* (Steindachner), and the modifying effects of cadmium and mercury. Biol. Trace Element Research. 50: 193-208.

Allen, P. 1995b. Accumulation profiles of lead and cadmium in the edible tissues of *Oreochromis aureus* during acute exposure. J. Fish Biol. 47: 559-568.

Allen, Y., P. Calow and D.J. Baird. 1995. A mechanistic model of contaminant-induced feeding inhibition on *Daphnia magna*. Environ. Toxicol. Chem. 14(9): 1625-1630.

Amiard, J.C., C. Metayer, J.P. Baud and F. Ribeyre. 1994. Influence of some ecological and biological factors on metal bioaccumulation in young oysters (*Crassostrea gigas* Thunberg) during their spat rearing. Water Res. 28(1): 219-231.

Amiard-Triquet, C., B. Berthet, C. Metayer and J.C. Amiard. 1986. Contribution to the ecotoxicological study of cadmium, copper and zinc in the mussel *Mytilus edulis*. Mar. Biol. 92: 7-13.

Amiard-Triquet, C, C. Metayer and J.C. Amiard. 1987. Etudes *in situ* et experimentales de l'eotoxicologie de quatre metaux (Cd, Pb, Cu, Zn) chez des algues et des mollusques gasteropodes brouteurs. Water, Air, Soil Pollut. 34: 11-30.

Amiard-Triquet, C., J.C. Amiard, B. Berthet and C. Metayer. 1988. Field and experimental study of the bioaccumulation of some trace metals in a coastal food chain: seston, oyster (*Crassostrea gigas*), drill (*Ocenebra erinacea*). Water Sci. Tech. 20(6/7): 13-21.

Anadu, D.I., G.A. Chapman, L.R. Curtis and R.A. Tubb. 1989. Effect of zinc exposure on subsequent acute tolerance to heavy metals in rainbow trout. Bull. Environ. Contam. Toxicol. 43: 329-336.

Anderson, B.G. 1948. The apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78: 96.

Anderson, R.L., et al. 1980. Survival and growth of *Tanytarsus dissimilis* (Chironomidae) exposed to copper, cadmium, zinc, and lead. Arch. Environ. Contam. Toxicol. 9: 329.

Anderson, R.V., et al. 1978. The distribution of Cd, Cu, Pb and Zn in the biota of two freshwater sites with different trace metal inputs. Holartic Ecol. 1: 377.

Andres, S., M. Baudrimont, Y. Lapaquellerie, F. Ribeyre, N. Maillet, C. Latouche and A. Boudou. 1999. Field transplantation of the freshwater bivalve *Corbicula fluminea* along a polymetallic contamination gradient (River Lot, France): I. Geochemical characteristics of sampling sites and cadmium and zinc bioaccumulation kinetics. Environ. Toxicol. Chem. 18(11): 2462-2471.

Andros, J.D. and R.R. Garton. 1980. Acute lethality of copper, cadmium, and zinc to northern squawfish. Trans. Am. Fish. Soc. 109: 235.

Annune, P.A., S.O. Ebele and A.A. Oladimeji. 1994. Acute toxicity of cadmium to juveniles of *Clarias gariepinus* (Teugels) and *Oreochromis niloticus* (Trewavas). J. Environ. Sci. Health. A29(7): 1357-1365.

Anonymous. 1950. Ohio River Valley Water Sanitation Commission, Subcommittee on Toxicities, Metal Finishing Industries Action Committee Report No. 3.

Arillo, A., et al. 1982. Biochemical effects of long-term exposure to Cr, Cd, Ni on rainbow trout (*Salmo gairdneri* Rich.): influence of sex and season. Chemosphere 11: 47.

Arillo, A., et al. 1984. Biochemical effects of long-term exposure to cadmium and copper on rainbow trout (*Salmo gairdneri*): validation of water quality criteria. Ecotoxicol. Environ. Safety 8: 106.

Arnac, M. and C. Lassus. 1985. Heavy metal accumulation (Cd, Cu, Pb and Zn) by smelt (*Osmerus mordax*) from the north shore of the St. Lawrence estuary. Water Res. 19(6): 725-734.

Arshaduddin, M., R. Yasmeen, M.M. Hussain and M.A. Khan. 1989. Effect of two heavy metals (lead and cadmium) on growth in the rotifer *Asplanchna intermedia*. Pollut. Res. 8(3): 129-128.

Asato, S.L. and D.J. Reish. 1988. The effects of heavy metals on the survival and feeding of *Holmesimysis costata* (Crustacea: Mysidacea). *In*: Proc. 7th Int. Symp. on Mar. Biol., California State University, Long Beach, CA: 113-120.

Attar, E.N. and E.J. Maly. 1982. Acute toxicity of cadmium, zinc, and cadmium-zinc mixtures to *Daphnia magna*. Arch. Environ. Contam. Toxicol. 11: 291.

Austen, M.C. and A.J. McEvoy. 1997. The use of offshore meiobenthic communities in laboratory microcosm experiments: response to heavy metal contamination. J. Exp. Mar. Biol. Ecol. 211: 247-261.

Avery, E.L., R.H. Dunstan and J.A. Nell. 1996. The detection of pollutant impact in marine environments: condition index, oxidative DNA damage, and their associations with metal bioaccumulation in the Sydney rock oyster *Saccostrea commercialis*. Arch. Environ. Contam. Toxicol. 31: 192-198.

Azeez, P.A. and D.K. Banerjee. 1987. Influence of light on chlorophyll, a content of blue-green algae treated with heavy metals. Bull. Environ. Contam. Toxicol. 38: 1062-1069.

Babich, H. and G. Stotzky. 1978. Effects of cadmium on the biota: influence of environmental factors. Adv. Appl. Microbiol. 23: 55-117.

Babich, H. and G. Stotzky. 1982. Influence of chloride ions on the toxicity of cadmium to fungi. Zbl. Bakt. Hyg., I. Abt. Orig. C. 3: 421.

Baby, K.V. and N.R. Menon. 1987. Salt forms of metals and their toxicity in the brown mussel *Perna indica* (Kuriakose and Nair). Indian J. Mar. Sci. 16(2): 107-109.

Bailey, H.C., J.L. Miller, M.J. Miller and B.S. Dhaliwal. 1995. Application of toxicity identification procedures to the echinoderm fertilization assay to identify toxicity in a municipal effluent. Environ. Toxicol. Chem. 14(12): 2181-2186.

Baillieul, M. and R. Blust. 1999. Analysis of the swimming velocity of cadmium-stressed *Daphnia magna*. Aquat. Toxicol. 44: 245-254.

Baird, D.J., I. Barber and P. Calow. 1990. Clonal variation in general responses of *Daphnia magna* Straus to toxic stress. I. Chronic life-history effects. Funct. Ecol. 4(3): 399-407.

Baird, D.J., I. Barber, M. Bradley, A.M.V.M. Soares and P. Calow. 1991. A comparative study of genotype sensitivity to acute toxic stress using clones of *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 21: 257-265.

Ball, I.R. 1967. The toxicity of cadmium to rainbow trout (*Salmo gairdnerii* Richardson). Water Res. 1: 805.

Balogh, K.V. and J. Salanki. 1984. The dynamics of mercury and cadmium uptake into different organs of *Anodonta cygnea* L. Water Res. 18(11): 1381-1387.

Bambang, Y., G. Charmantier, P. Thuet and J.P. Trilles. 1994. Effect of cadmium on survival and osmoregulation of various developmental stages of the shrimp *Penaeus japonicus* (Crustacea: Decapoda). Mar. Biol. 123: 443-450.

Barata, C., D.J. Baird and S.J. Markich. 1998. Influence of genetic and environmental factors on the tolerance of *Daphnia magna* Straus to essential and non-essential metals. Aquat. Toxicol. 42: 115-137.

Barnthouse, L.W., G.W. Suter II, A.E. Rosen and J.J. Beauchamp. 1987. Estimating responses of fish populations to toxic contaminants. Environ. Toxicol. Chem. 6: 811-824.

Barque, J., A. Abahamid, Y. Bourezgui, H. Chacun and J. Bonaly. 1995. Growth responses of achlorophyllous *Euglena gracilis* to selected concentrations of cadmium and pentachlorophenol. Arch. Environ. Contam. Toxicol. 28: 8-12.

Bartlett, L., et al. 1974. Effects of copper, zinc and cadmium on *Selenastrum capricornutum*. Water Res. 8: 179.

Bartsch, M.R., W.G. Cope and R.G. Rada. 1999. Effects of cadmium-spiked sediment on cadmium accumulation and bioturbation by nymphs of the burrowing mayfly *Hexagenia bilineata*. Water, Air, Soil Pollut. 109: 277-292.

Battaglini, P., G. Andreozzi, R. Antonucci, N. Arcamone, P. De Giroloamo, L. Ferrara and G. Gargiulo. 1993. The effects of cadmium on the gills of the goldfish *Carassius auratus* L.: metal uptake and histochemical changes. Comp. Biochem. Physiol. 104C(2): 239-247.

Baudrimont, M., J. Metivaud, R. Maury-Brachet, F. Ribeyre and A. Boudou. 1997. Bioaccumulation and metallothionein response in the asiatic clam (*Corbicula fluminea*) after experimental exposure to cadmium and inorganic mercury. Environ. Toxicol. Chem. 16(10): 2096-2105.

Bay, S, R. Burgess and D. Nacci. 1993. Status and applications of echinoid (*Phylum echinodermata*) toxicity test methods. Environ. Toxicol. Risk. Assess., ASTM STP 1179, W.G. Landis, J.S. Hughes and M.A. Lewis (eds.), American Society for Testing and Materials, Philadelphia. pp. 281-302.

Beattie, J.H. and D. Pascoe. 1978. Cadmium uptake by rainbow trout, *Salmo gairdneri* eggs and alevins. J. Fish Biol. 13: 631.

Bednarz, T. and H. Warkowska-Dratnal. 1983/1984. Toxicity of zinc, cadmium, lead, copper, and their mixture for *Chlorella pyrenoidosa* Chick. Acta Hydrobiol. 25/26(3/4): 389-400.

Beiras, R., E. His and M.N.L. Seaman. 1998. Effects of storage temperature and duration on toxicity of sediments assessed by *Crassostrea gigas* oyster embryo bioassay. Environ. Toxicol. Chem. 17(10): 2100-2105.

Belabed, W., N. Kestali, S. Semsari and A. Gaid. 1994. Toxicity study of some heavy metals with daphnia test. Tech. Sci. Methods. 6: 331-336.

Belanger, S.E. and D.S. Cherry. 1990. Interacting effects of pH acclimation, pH, and heavy metals on acute and chronic toxicity to *Ceriodaphnia dubia* (Cladocera). J. Crustacean Biol. 10(2): 225-235.

Bellavere, C. and J. Gorbi. 1981. A comparative analysis of acute toxicity of chromium, copper and cadmium to *Daphnia magna*, *Biomphalaria glabrata*, and *Brachydanio rerio*. Environ. Technol. Letters 2: 119.

Bendell-Young, L.I. 1994. Comparison of metal concentrations in the fore and hindguts of the crayfish *Cambarus bartoni* and *Orconectes virilis* and implications regarding metal absorption efficiencies. Bull. Environ. Contam. Toxicol. 53: 844-851.

Bendell-Young, L.I. 1999. Application of a kinetic model of bioaccumulation across a pH and salinity gradient for the prediction of cadmium uptake by the sediment dwelling chironomidae. Environ. Sci. Technol. 33: 1501-1508.

Bendell-Young, L.I., H.H. Harvey and J.F. Young. 1986. Accumulation of cadmium by white suckers (*Catostomus commersoni*) in relation to fish growth and lake acidification. Can. J. Fish. Aquat. Sci. 43: 806-811.

Bengtsson, B. 1978. Use of harpacticoid copepod in toxicity tests. Mar. Pollut. Bull. 9: 238.

Bengtsson, B.E. and B. Bergstrom. 1987. A flow-through fecundity test with *Nitocra spinipes* (Harpacticoidea crustacea) for aquatic toxicity. Ecotoxicol. Environ. Safety. 14: 260-268.

Benoit, D.A., et al. 1976. Toxic effects of cadmium on three generations of brook trout (*Salvelinus fontinalis*). Trans. Am. Fish. Soc. 105:550.

Bentley, P.J. 1991. Accumulation of cadmium by channel catfish (*Ictalurus punctatus*): influx from environmental solutions. Comp. Biochem. Physiol. 99C: 527-529.

Berglind, R. 1985. The effects of cadmium on ala-d activity, growth and haemoglobin content in the water flea, *Daphnia magna*. Comp. Biochem. Physiol. 80C(2): 407-410.

Berglind, R. 1986. Combined and separate effects of cadmium, lead and zinc on ala-d activity, growth and hemoglobin content in *Daphnia magna*. Environ. Toxicol. Chem. 5: 989-995.

Bernds, D, D. Wubben and G.P. Zauke. 1998. Bioaccumulation of trace metals in polychaetes from the German Wadden Sea: evaluation and verification of toxicokinetic models. Chemosphere. 37(13): 2573-2587.

Bertram, P.E. and B.A. Hart. 1979. Longevity and reproduction of *Daphnia pulex* (deGeer) exposed to cadmium-contaminated food or water. Environ. Pollut. 19: 295.

Bervoets, L., R. Blust and R. Verheyen. 1995. The uptake of cadmium by the midge larvae *Chironomus riparius* as a function of salinity. Aquat. Toxicol. 33: 227-243.

Bervoets, L, R. Blust and R. Verheyen. 1996. Effect of temperature on cadmium and zinc uptake by the midge larvae *Chironomus riparius*. Arch. Environ. Contam. Toxicol. 31: 502-511.

Besser, J.M. and C.F. Rabeni. 1987. Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates. Environ. Toxicol. Chem. 6: 879-890.

Biesinger, K.E. and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res. Board Can. 29: 1691.

Biesinger, K.E., G.M. Christensen and J.T. Fiandt. 1986. Effects of metal salt mixtures on *Daphnia magna* reproduction. Ecotoxicol. Environ. Safety. 11: 9-14.

Bigelow, L.K. and D.C. Lasenby. 1991. Particle size selection in cadmium uptake by the opossum shrimp, *Mysis relicta*. Bull. Environ. Contam. Toxicol. 47: 790-796.

Birge, W.J. 1978. Aquatic toxicology of trace elements of coal and fly ash. *In:* J.H. Thorp and J.W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Systems. CONF-771114. National Technical Information Service, Springfield, Virginia. p. 219.

Birge, W.J., et al. 1978. Embryo-larval bioassay on inorganic coal elements and *in situ* biomonitoring of coal-waste effluents. *In:* D.E. Samuel, et al. (eds.), Surface Mining and Fish/Wildlife Needs in the Eastern United States. PB 298353. National Technical Information Service, Springfield, Virginia. p. 97.

Birge, W.J., et al. 1979. The effects of mercury on reproduction of fish and amphibians. *In:* J.O. Nriagu (ed.), The Biochemistry of Mercury in the Environment. Elsevier/North-Holland, New York. p. 629.

Birge, W.J., et al. 1980. Aquatic toxicity tests on inorganic elements occurring in oil shale, *In:* C. Gale (ed.), Oil Shale Symposium: Sampling, Analysis and Quality Assurance. EPA-600/9-80-022. National Technical Information Service, Springfield, Virginia. p. 519.

Birge, W.J., et al. 1981. The reproductive toxicology of aquatic contaminants. *In:* J. Saxena and F. Fisher (eds.), Hazard Assessment of Chemicals: Current Developments. Vol. 1. Academic Press, New York. p. 59.

Birge, W.J., et al. 1983. Induction of tolerance to heavy metals in natural and laboratory populations of fish. PB84-111756. National Technical Information Service, Springfield, Virginia.

Birge, W.J., J.A. Black and A.G. Westerman. 1985. Short-term fish and amphibian embryo-larval tests for determining the effects of toxicant stress on early life stages and estimating chronic values for single compounds and complex effluents. Environ. Toxicol. Chem. 4: 807-821.

Birmelin, C., J. Cuzin-Roudy, M. Romeo, M. Gnassia-Barelli and S. Puiseux-Dao. 1995. The mysid *Siriella armata* as a test organisms in toxicology: effects of cadmium. Mar. Environ. Res. 39: 317-320.

Bishop, W.E. and A.W. McIntosh. 1981. Acute lethality and effects of sublethal cadmium exposure on ventilation frequency and cough rate of bluegill (*Lepomis macrochirus*). Arch. Environ. Contam. Toxicol. 10: 519.

Bittner, M.A. 1994. The effect of dissolved natural organics on the chronic toxicity of cadmium to *Mysidopsis bahia molenock* (Crustacea: Mysidacea). George Mason University (USA), 209 pp.

Bitton, G., K. Jung and B. Koopman. 1994. Evaluation of a microplate assay specific for heavy metal toxicity. Arch. Environ. Contam. Toxicol. 27: 25-28.

Bitton, G., K. Rhodes, B. Koopman and M. Cornejo. 1995. Short-term toxicity assay based on daphnid feeding behavior. Water Environ. Res. 67(3): 290-293.

Bitton, G., K. Rhodes and B. Koopman. 1996. Ceriofast™: an acute toxicity test based on *Ceriodaphnia dubia* feeding behavior. Environ. Toxicol. Chem. 15(2): 123-125.

Bjerregaard, P. 1982. Accumulation of cadmium and selenium and their mutual interaction in the shore crab *Carcinus maenas*. Aquat. Toxicol. 2: 113.

Bjerregaard, P. 1985. Effect of selenium on cadmium uptake in the shore crab *Carcinus maenas* (L.). Aquat. Toxicol. 7: 177-189.

Bjerregaard, P. 1991. Relationship between physiological condition and cadmium accumulation in *Carcinus maenas* (L.). Comp. Biochem. Physiol. 99A(1/2): 75-83.

Bjerregaard, P. and M.H. Depledge. 1994. Cadmium accumulation in *Littorina littorea*, *Mytilus edulis* and *Carcinus maenas*: the influence of salinity and calcium ion concentrations. Mar. Biol. 119: 385-395.

Black, J.A. and W.J. Birge. 1980. An avoidance response bioassay for aquatic pollutants. PB80-180490. National Technical Information Service, Springfield, Virginia.

Blickens, E.A.M. 1978. Cadmium induced histopathological changes in the gills of the brown bullhead *Ictalurus nebulosus* (Lesueur). Ph.D. Thesis. New York University.

Block, M. and A.W. Glynn. 1992. Influence of xanthates on the uptake of ^{109}Cd by Eurasian dace (*Phoxinus phoxinus*) and rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 11: 873-879.

Block, M. and P. Part. 1992. Uptake of ^{109}Cd by cultured gill epithelial cells from rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 23: 137-151.

Block, M, A.W. Glynn and P. Part. 1991. Xanthate effects on cadmium uptake and intracellular distribution in rainbow trout (*Oncorhynchus mykiss*) gills. Aquat. Toxicol. 20: 267-284.

Blondin, G.A., L.M. Knobeloch, H.W. Read and J.M. Harkin. 1989. An *in vitro* submitochondrial bioassay for predicting acute toxicity in fish. Aquat. Toxicol. Environ. Fate. ASTM STP 1007, G.W. Suter II and M.A. Lewis (eds.), American Society for Testing and Materials, Philadelphia. 11: 551-563.

Bodar, C.W.M., I. Van der Sluis, P.A. Voogt and D.I. Zandee. 1988a. Effects of cadmium on consumption, assimilation and biochemical parameters of *Daphnia magna*: possible implications for reproduction. Comp. Biochem. Physiol. 90C(2): 341-346.

Bodar, C.W.M., C.J. Van Leeuwen, P.A. Voogt and D.I. Zandee. 1988b. Effect of cadmium on the reproduction strategy of *Daphnia magna*. Aquat. Toxicol. 12: 301-310.

Bodar, C.W.M., A.V.D. Zee, P.A. Voogt, H. Wynne and D.I. Zandee. 1989. Toxicity of heavy metals to early life stages of *Daphnia magna*. Ecotoxicol. Environ. Safety. 17: 333-338.

Bodar, C.W.M., P.A. Voogt and D.I. Zandee. 1990a. Ecdysteroids in *Daphnia magna*: their role in moulting and reproduction and their levels upon exposure to cadmium. Aquat. Toxicol. 17: 339-350.

Bodar, C.W.M., I. Van der Sluis, J.C.P., Van Montfort, P.A. Voogt and D.I. Zandee. 1990b. Cadmium resistance in *Daphnia magna*. Aquat. Toxicol. 16: 5633-40.

Bolanos, L., M. Garcia-Gonzalez, P. Mateo and I. Bonilla. 1992. Differential toxicological response to cadmium in *Anabaena* strain PCC 7119 grown with NO_3^- or NH_4^+ as nitrogen source. J. Plant Physiol. 140: 345-349.

Borchardt., T. 1983. Influence of food quantity on the kinetics of cadmium uptake and loss via food and seawater in *Mytilus edulis*. Mar. Biol. 76: 67-76.

Borgmann, U. and K.M. Ralph. 1986. Effects of cadmium, 2,4-dichlorophenol, and pentachlorophenol on feeding, growth, and particle-size-conversion efficiency of white sucker larvae and young common shiners. Arch. Environ. Contam. Toxicol. 15: 473-480.

Borgmann, U., K.M. Ralph and W.P. Norwood. 1989. Toxicity test procedures for *Hyalella azteca*, and chronic toxicity of cadmium and pentachlorophenol to *H. azteca*, *Gammarus fasciatus*, and *Daphnia magna*. Arch. Environ. Contam. Toxicol. 18: 756-764.

Borgmann, U., W.P. Norwood and I.M. Babirad. 1991. Relationship between chronic toxicity and bioaccumulation of cadmium in *Hyalella azteca*. Can. J. Fish. Aquat. Sci. 48: 1055-1060.

Bosnak, A.D. and E.L. Morgan. 1981. Acute toxicity of cadmium, zinc, and total residual chlorine to epigean and hypogean isopods (Asellidae). Natl. Speleological Soc. Bull. 43: 12.

Bouquegneau, J.M. and M. Martoja. 1982. La teneur en cuivre et son degre de complexation chez quatre gasteropodes marins. Donnees sur le cadmium et zinc. Oceanologica Acta 5: 219.

Boutet, C. and C. Chaisemartin. 1973. Specific toxic properties of metallic salts in *Austropotamobius pallipes pallipes* and *Orconectes limosus*. C.R. Soc. Biol. 167: 1933.

Bowen, W.J. and D.W. Engel. 1996. Effects of protracted cadmium exposure on gametes of the purple sea urchin, *Arbacia punctulata*. Bull. Environ. Contam. Toxicol. 56: 493-499.

Boyden, C.R. 1977. Effect of size upon metal content of shellfish. J. Mar. Biol. Assoc. U.K. 57: 675.

Bozeman, J., B. Koopman and G. Bitton. 1989. Toxicity testing using immobilized algae. Aquat. Toxicol. 14: 345-352.

Braginskly, L.P. and E.P. Shcherban. 1978. Acute toxicity of heavy metals to aquatic invertebrates at different temperatures. Hydrobiol. J. 14(6): 78.

Brand, L.E., W.G. Sunda and R.R.L. Guillard. 1986. Reduction of marine phytoplankton reproduction rates by copper and cadmium. J. Exp. Mar. Biol. Ecol. 96: 225-250.

Brent, R.N. and E.E. Herricks. 1998. Postexposure effects of brief cadmium, zinc, and phenol exposures on freshwater organisms. Environ. Toxicol. Chem. 17(10): 2091-2099.

Bresler, V. and V. Yanko. 1995. Acute toxicity of heavy metals for benthic epiphytic foraminifera *Pararotalia spinigera* (Le Calvez) and influence of seaweed-derived DOC. Environ. Toxicol. Chem. 14(10): 1687-1695.

Bressan, M. and R. Brunetti. 1988. The effects of nitriloacetic acid, Cd and Hg on the marine algae *Dunaliella tertiolecta* and *Isochrysis galbana*. Water Res. 22(5): 553-556.

Bringmann, G. 1975. Determination of the biologically harmful effect of water pollutants by means of the retardation of cell proliferation of the blue algae *Microcystis*. Gesundheits-Ing. 96: 238.

Bringmann, G. 1978. Determination of the biological toxicity of waterbound substances towards protozoa. I. bacteriovorous flagellates (model organism: *Entosiphon sulcatum* Stein). Z. Wasser Abwasser Forsch. 11: 210.

Bringmann, G. and R. Kuhn. 1959a. The toxic effects of waste water on aquatic bacteria, algae, and small crustaceans. Gesundheits-Ing. 80: 115.

Bringmann, G. and R. Kuhn. 1959b. Water toxicology studies with protozoans as test organisms. Gesundheits-Ing. 80: 239.

Bringmann, G. and R. Kuhn. 1976. Comparative results of the damaging effects of water pollutants against bacteria (*Pseudomonas putida*) and blue algae (*Microcystis aeruginosa*). Gas-Wasserfach, Wasser-Abwasser 117: 410.

Bringmann, G. and R. Kuhn. 1977a. Limiting values for the damaging action of water pollutants to bacteria (*Pseudomonas putida*) and green algae (*Scenedesmus quadricauda*) in the cell multiplication inhibition test. Z. Wasser Abwasser Forsch. 10: 87.

Bringmann, G. and R. Kuhn. 1977b. Results of damaging effect of water pollutants on *Daphnia magna*. Z. Wasser Abwasser Forsch. 10: 161.

Bringmann, G. and R. Kuhn. 1978a. Limiting values for the noxious effects of water pollutant material to blue algae (*Microcystis aeruginosa*) and green algae (*Scenedesmus quadricauda*) in cell propagation inhibition test. Vom Wasser 50: 45.

Bringmann, G. and R. Kuhn. 1978b. Testing of substances for their toxicity threshold: model organisms *Microcystis (Diplocystis) aeruginosa* and *Scenedesmus quadricauda*. Mitt. Int. Ver. Theor. Angew. Limnol. 21: 275.

Bringmann, G. and R. Kuhn. 1979. Comparison of toxic limiting concentrations of water contaminants toward bacteria, algae, and protozoa in the cell-growth inhibition test. Haustech. Bauphys. Umwelttech. 100: 249.

Bringmann, G. and R. Kuhn. 1980a. Determination of the harmful biological effect of water pollutants on protozoa. II. bacteriovorous ciliates. Z. Wasser Abwasser Forsch. 13: 26.

Bringmann, G. and R. Kuhn. 1980b. Comparison of the toxicity thresholds of water pollutants to bacteria, algae, and protozoa in the cell multiplication inhibition test. Water Res. 14: 231.

Bringmann, G. and R. Kuhn. 1981. Comparison of the effects of harmful substances on flagellates as well as ciliates and on halozoic bacteriophagous and saprozoic protozoa. Gas-Wasserfach, Wasser-Abwasser 122: 308.

Bringmann, G. and R Kuhn. 1982. Results of toxic action of water pollutants on *Daphnia magna* Straus tested by an improved standardized procedure. Z. Wasser Abwasser Forsch. 15: 1.

Bringmann, G., et al. 1980. Determination of biological damage from water pollutants to protozoa. III. saprozoic flagellates. Z. Wasser Abwasser Forsch. 13: 170.

Brkovic-Popovic, I. and M. Popovic. 1977a. Effects of heavy metals on survival and respiration rate of tubificid worms: Part I-effects on survival. Environ. Pollut. 13:65.

Brkovic-Popovic, I. and M. Popovic. 1977b. Effects of heavy metals on survival and respiration rate of tubificid worms: Part II-effects on respiration rate. Environ. Pollut. 13: 93.

Brooks, A.W., L. Maltby, A.J. Saul and P. Calow. 1996. A simple indoor artificial stream system designed to study the effects of toxicant pulses on aquatic organisms. Water Res. 30(2): 285-290.

Brouwer, M, D.W. Engel, J. Bonaventura and G.A. Johnson. 1992. In vivo magnetic resonance imaging of the blue crab, *Callinectes sapidus*: effect of cadmium accumulation in tissues on proton relaxation properties. J. Exp. Zool. 263: 32-40.

Brown, B. and M. Ahsanullah. 1971. Effect of heavy metals on mortality and growth. Mar. Pollut. Bull. 2: 182.

Brown, A.F. and D. Pascoe. 1988. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates: V. The acute toxicity of cadmium to twelve species of predatory macroinvertebrates. Arch. Hydrobiol. 114(2): 311-319.

Brown, D.A., et al. 1984. Detoxification/toxification of cadmium in scorpionfish (*Scorpaena quttata*): acute exposure. Aquat. Toxicol. 5: 93.

Brown, M.W., D.G. Thomas, D. Shurben, J.F. De L.G. Solbe, J. Kay and A. Cryer. 1986. A comparison of the differential accumulation of cadmium in the tissues of three species of freshwater fish, *Salmo Gairdneri*, *Rutilus rutilus* and *Noemacheilus barbatulus*. Comp. Biochem. Physiol. 84C(2): 213-217.

Brown, V., D. Shurben, W. Miller and M. Crane. 1994. Cadmium toxicity to rainbow trout *Oncorhynchus mykiss* Walbaum and brown trout *Salmo trutta* L. over extended exposure periods. Ecotoxicol. Environ. Safety. 29: 38-46.

Brunetti, R., M. Marin, M. Bressan, M. Zordan and A. Soggia. 1991. Effects of the chelating agent nitrilotriacetic acid (NTA) on the toxicity of metals (Cd, Cu, Zn and Pb) in the sea urchin *Paracentrotus lividus* LMK. Vie Milieu. 41(1): 39-43.

Bryan, G.W. 1971. The effects of heavy metals (other than mercury) on marine and estuarine organisms. Proc. R. Soc. London B. 177: 389.

Bryan, G.W., et al. 1983. An assessment of the gastropod, *Littorina littorea*, as an indicator of heavy metal contamination in United Kingdom estuaries. J. Mar. Biol. Assoc. U.K. 63: 327.

Bryan, M.D., G.J. Atchison and M.B. Sandheinrich. 1995. Effects of cadmium on the foraging behavior and growth of juvenile bluegill, *Lepomis macrochirus*. Can. J. Fish. Aquat. Sci. 53: 1630-1638.

Buckley, J.A., G.A. Yoshida, N.R. Wells and R.T. Aquino. 1985. Toxicities of total and chelex-labile cadmium to salmon in solutions of natural water and diluted sewage with potentially different cadmium complexing capacities. Water Res. 19(12): 1549-1554.

Buhl, K.J. 1997. Relative sensitivity of three endangered fishes, Colorado squawfish, bonytail, and razorback sucker, to selected metal pollutants. Ecotoxicol. Environ. Safety. 37: 186-192.

Buhl, K.J. and S.J. Hamilton. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicol. Environ. Safety. 22: 184-197.

Buikema, A.L., Jr., et al. 1974a. Rotifers as monitors of heavy metal pollution in water. Bulletin 71. Virginia Water Resources Research Center, Blacksburg, Virginia.

Buikema, A.L., Jr., et al. 1974b. Evaluation of *Philodina acuticornis* (Rotifera) as a bioassay organism for heavy metals. Water Res. Bull. 10: 648.

Buikema, A.L., Jr., et al. 1977. Rotifer sensitivity to combinations of inorganic water pollutants. Bulletin 92. Virginia Water Resources Research Center, Blacksburg, Virginia.

Burdin, K.S. and K.T. Bird. 1994. Heavy metal accumulation by carrageenan and agar producing algae. Bot. Mar. 37: 467-470.

Burnison, G., et al. 1975. Toxicity of cadmium to freshwater algae. Proc. Can. Fed. Biol. Soc. 18: 46.

Burrell, D.C. and D. Weihs. 1983. Uptake of cadmium by marine bacteria and transfer to a deposit feeding clam. Sea Grant Report 83-5. University of Alaska, Fairbanks, Alaska.

Burton, D.T. and D.J. Fisher. 1990. Acute toxicity of cadmium, copper, zinc, ammonia, 3,3'-dichlorobenzidine, 2,6-dichloro-4-nitroaniline, methylene chloride, and 2,4,6-trichlorophenol to juvenile grass shrimp and killifish. Bull. Environ. Contam. Toxicol. 44: 776-783.

Busch, D, T. Lucker and W. Wosniok. 1998. Effects of changing salt concentrations and other physical-chemical parameters on bioavailability and bioaccumulation of heavy metals in exposed *Dreissena polymorpha* (Pallas, 1771). Limnologica. 28(3): 263-274.

Cairns, J. Jr., J.R. Pratt, B.R. Niederlehner and P.V. McCormick. 1986. A simple, cost-effective multispecies toxicity test using organisms with a cosmopolitan distribution. Environ. Monit. Assess. 6: 207-220.

Calabrese, A., et al. 1973. The toxicity of heavy metals to embryos of the American oyster *Crassostrea virginica*. Mar. Biol. 18: 162.

Calabrese, A., et al. 1975. Sublethal physiological stress induced by cadmium and mercury in the winter flounder, *Pseudopleuronectes americanus*. *In:* J.H. Koeman and J.J.T.W.A. Strik (eds.), Sublethal Effects of Toxic Chemicals in Aquatic animals. Elsevier, New York. p. 15.

Calevro, F., S. Campani, M. Ragghianti, S. Bucci and G. Mancino. 1998a. Tests of toxicity and teratogenicity in biphasic vertebrates treated with heavy metals (Cr^{3+}, Al^{3+}, Cd^{2+}). Chemosphere. 37(14-15): 3011-3017

Calevro, F, C. Filippi, P. Deri, C. Albertosi and R. Batistoni. 1998b. Toxic effects of aluminum, chromium and cadmium in intact and regenerating freshwater planarians. Chemosphere. 37(4): 651-659.

Callahan, M.A., et al. 1979. Water-related environmental fate of 129 priority pollutants. Vol. I. EPA-440/4-79-029a. National Technical Information Service, Springfield, Virginia.

Campbell, J. and R.D. Evans. 1991. Cadmium concentrations in the freshwater mussel (*Elliptio complanata*) and their relationship to water chemistry. Arch. Environ. Contam. Toxicol. 20: 125-131.

Camusso, M., L. Vigano and R. Balestrini. 1995. Bioconcentration of trace metals in rainbow trout: a field study. Ecotoxicol. Environ. Safety. 31: 133-141.

Canli, M. and R.W. Furness. 1993. Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster *Nephrops norvegicus*. Mar. Environ. Res. 36: 217-236.

Canli, M. and R.W. Furness. 1995. Mercury and cadmium uptake from seawater and from food by the Norway lobster *Nephrops norvegicus*. Environ. Toxicol. Chem. 14(5): 819-828.

Canterford, G.S. and D.R. Canterford. 1980. Toxicity of heavy metals to the marine diatom *Ditylum brightwellii* (West) Grunow: correlation between toxicity and metal speciation. J. Mar. Biol. Assoc. U.K. 60: 227.

Canton, J.H. and D.M.M. Adema. 1978. Reproducibility of short-term and reproduction toxicity experiments with *Daphnia magna* and comparison of the sensitivity of *Daphnia magna* with *Daphnia pulex* and *Daphnia cucullata* in short-term experiments. Hydrobiol. 59: 135.

Canton, J.H. and W. Slooff. 1979. A proposal to classify compounds and to establish water quality based on laboratory data. Ecotoxicol. Environ. Safety 3: 126.

Canton, J.H. and W. Slooff. 1982. Toxicity and accumulation studies of cadmium (Cd^{2+}) with freshwater organisms of different trophic levels. Ecotoxicol. Environ. Safety 6: 113.

Cardin, J.A. 1982. Memorandum to J.H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Carlisle, D.M. and W.H. Clements. 1999. Sensitivity and variability of metrics used in biological assessments of running waters. Environ. Toxicol. Chem. 18(2): 285-291.

Carlson, A.R., et al. 1982. Cadmium and endrin toxicity to fish in waters containing mineral fibers. EPA-600/3-82-053. National Technical Information Service, Springfield, Virginia.

Carmichael, N.G. and B.A. Fowler. 1981. Cadmium accumulation and toxicity in the kidney of the bay scallop *Argopecten irradians*. Mar. Biol. 65: 35.

Carpene, E. and L. Boni. 1992. Effects of heavy metals on the algae *Nitzschia closterium* and *Prorocentrum micans*. Sci. Total Environ. Supplemental Vol.: 921-927.

Carr, R.S. and J.M. Neff. 1982. Biochemical indices of stress in the sandworm *Neanthes virens* (Sars). II. sublethal responses to cadmium. Aquat. Toxicol. 2: 319.

Carr, R.S., J.W. Williams, F.I. Saksa, R.L. Buhl and J.M. Neff. 1985. Bioenergetic alterations correlated with growth, fecundity and body burden of cadmium for mysids (*Mysidopsis bahia*). Environ. Toxicol. Chem. 4: 181-188.

Carrier, R. and T.L. Beitinger. 1988a. Reduction in thermal tolerance of *Notropis lutrensis* and *Pimephales promelas* exposed to cadmium. Water Res. 22(4): 511-515.

Carrier, R. and T.L. Beitinger. 1988b. Resistance of temperature tolerance ability of green sunfish to cadmium exposure. Bull. Environ. Contam. Toxicol. 40: 475-480.

Carroll, J.J., S.J. Ellis and W.S. Oliver. 1979. Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*). Bull. Environ. Contam. Toxicol. 22:575-581.

Casini, S. and M.H. Depledge. 1997. Influence of copper, zinc, and iron on cadmium accumulation in the Talitrid amphipod, *Platorchestia platensis*. Bull. Environ. Contam. Toxicol. 59: 500-506.

Cassini, A, L. Tallandini, N. Favero and V. Albergoni. 1986. Cadmium bioaccumulation studies in the freshwater molluscs *Anodonta cygnea* and *Unio elongatulus*. Comp. Biochem. Physiol. 84C(1): 35-41.

Castano, A., M.J. Cantarino, P. Castillo and J.V. Tarazona. 1996. Correlations between the RTG-2 cytotoxicity test EC50 and *in vivo* LC50 rainbow trout bioassay. Chemosphere. 32(11): 2141-2157.

Castille, F.L., Jr. and A.L. Lawrence. 1981. The effects of EDTA (ethylenedinitrotetraacetic acid) on the survival and development of shrimp nauplii (*Penaeus stylirostris* Stimpson) and the interactions of EDTA and the toxicities of cadmium, calcium, and phenol. J. World Maricul. Soc. 12: 292.

Cearley, J.E. and R.L. Coleman. 1973. Cadmium toxicity and accumulation in southern naiad. Bull. Environ. Contam. Toxicol. 9: 100.

Cearley, J.E. and R.L. Coleman. 1974. Cadmium toxicity and bioconcentration in largemouth bass and bluegill. Bull. Environ. Contam. Toxicol. 11: 146.

Centeno, M.D., L. Brendonck and G. Persoone. 1993. Cyst-based toxicity tests. III. Development and standardization of an acute toxicity test with the freshwater anostracan crustacean *Streptocephalus proboscideus*. *In:* A.M.V.M. Soares and P. Calow (eds.). Progress in Standardization of Aquatic Toxicity Tests. Lewis Publishers. pp 37-55.

Centeno, M.D.F., G. Persoone and M.P.Goyvaerts. 1995. Cyst-based toxicity tests. IX. The potential of Thamnocephalus platyurus as test species in comparison with *Streptocephalus proboscideus* (Crustacea: branchiopoda: anostraca). Environ. Toxicol. Water Qual. 10(4): 275-282.

Chagnon, N.L. and S.I. Guttman. 1989. Differential survivorship of allozyme genotypes in mosquitofish populations exposed to copper or cadmium. Environ. Toxicol. Chem. 8: 319-326.

Chan, H.M. 1988. Accumulation and tolerance to cadmium, copper, lead and zinc by the green mussel *Perna viridis*. Mar. Ecol. Prog. Ser. 48: 295-303.

Chan, H.M., P. Bjerregaard, P.S. Rainbow, M.H. Depledge. 1992. Uptake of zinc and cadmium by two populations of shore crabs *Carcinus maenas* at different salinities. Mar. Ecol. Prog. Ser. 86: 91-97.

Chan, K., et al. 1981. Effects of polyethylene glycol on growth and cadmium accumulation of *Chlorella salina* CU-1. Chemosphere 10: 985.

Chander, G.P., N.V. Madhav and Vidyavati. 1991. Response of *Pithophora oedogonia* to cadmium. Acta Botanica Indica. 19: 240-242.

Chandini, T. 1988a. Changes in food (*Chlorella*) levels and the acute toxicity of cadmium to *Daphnia carinata* (daphnidae) and *Echinisca triserialis* (macrothricidae) (Crustacea: cladocera). Bull. Environ. Contam. Toxicol. 41: 398-403.

Chandini, T. 1988b. Effects of different food (*Chlorell*a) concentrations on the chronic toxicity of cadmium to survivorship, growth and reproduction of *Echinisca triserialis* (crustacea: cladocera). Environ. Pollut. 54: 139-154.

Chandini, T. 1989. Survival, growth and reproduction of *Daphnia carinata* (crustacea: cladocera) exposed to chronic cadmium stress at different food (*Chlorella*) levels. Environ. Pollut. 60: 29-45.

Chandini, T. 1991. Reproductive value and the cost of reproduction in *Daphnia carinata* and *Echinisca triserialis* (crustacea: cladocera) exposed to food and cadmium stress. Bull. Environ. Contam. Toxicol. 47: 76-83.

Chandra, P. and P. Garg. 1992. Absorption and toxicity of chromium and cadmium in *Limnanthemum cristatum* Griseb. Sci. Total Environ. 125: 175-183.

Chang, M., H.C. Lin and P. Hwang. 1998. Ca^{2+} uptake and Cd^{2+} accumulation in larval tilapia (*Oreochromis mossambicus*) acclimated to waterborne Cd^{2}. Am. J. Physiol. 27(6): 1570-1577.

Chapman, G.A. 1975. Toxicity of copper, cadmium and zinc to Pacific Northwest salmonids. U.S. EPA, Corvallis, Oregon.

Chapman, G.A. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. Trans. Am. Fish. Soc. 107: 841.

Chapman, G.A. 1982. Letter to C.E. Stephan. U.S. EPA, Corvallis, Oregon. December 6.

Chapman, G.A. and D.G. Stevens. 1978. Acutely lethal levels of cadmium, copper, and zinc to adult male coho salmon and steelhead. Trans. Am. Fish. Soc. 107: 837.

Chapman, G.A., S. Ota and F. Recht. Manuscript. Effects of water hardness on the toxicity of metals to *Daphnia magna*. U.S. EPA, Corvallis, Oregon.

Chapman, P.M., et al. 1982. Relative tolerances of selected aquatic oligochaetes to individual pollutants and environmental factors. Aquat. Toxicol. 2: 47.

Chapman, W.H., et al. 1968. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. National Technical Information Service, Springfield, Virginia.

Charpentier, S., J. Garnier and R. Flaugnatti. 1987. Toxicity and bioaccumulation of cadmium in experimental cultures of duckweed, *Lemna polyrrhiza* L. Bull. Environ. Contam. Toxicol. 38: 1055-1061.

Chattopadhyay, S. K. Anam and A.K. Aditya. 1995. Bioassay evaluation of acute toxicity levels of mercuric chloride and cadmium chloride on the early growing stages of *Labeo rohita*. J. Ecobiol. 7(1): 41-47.

Chawla, G., J. Singh and P.N. Viswanathan. 1991. Effect of pH and temperature on the uptake of cadmium by *Lemna minor* L. Bull. Environ. Contam. Toxicol. 47: 84-90.

Chen, C.Y., K.C. Lin and D.T. Yang. 1997. Comparison of the relative toxicity relationships based on batch and continuous algal toxicity tests. Chemosphere. 35(9): 1959-1965.

Cheung, C.C.C. and P.K.S. Lam. 1998. Effect of cadmium on the embryos and juveniles of a tropical freshwater snail, *Physa acuta* (Draparnaud, 1805). Water Sci. Tech. 38(7): 263-270.

Chitguppa, R., K.H. Chu and M.A. Hashim. 1997. Reusability of seaweed biosorbent in multiple cycles of cadmium adsorption and desorption. Biotech. Techniques 11(6): 371-373.

Chou, C.L. and J.F. Uthe. 1991. Effect of starvation on trace metal levels in blue mussels (*Mytilus edulis*). Bull. Environ. Contam. Toxicol. 46: 473-478.

Chou, C.L., J.F. Uthe, J.D. Castell and J.C. Kean. 1987. Effect of dietary cadmium on growth, survival, and tissue concentrations of cadmium, zinc, copper, and silver in juvenile american lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. 44: 1443-1450.

Christoffers, D. and D.E.W. Ernst. 1983. The *in-vivo* fluorescence of *Chlorella fusca* as a biological test for the inhibition of photosynthesis. Toxicol. Environ. Chem. 7: 61-71.

Clausen, P.S., P. Bjerregaard and M.H. Depledge. 1993. Passive and active cadmium uptake in the isolated gills of the shore crab, *Carcinus maenas* (L.). Chemosphere. 26(12): 2209-2219.

Clubb, R.W., et al. 1975. Acute cadmium toxicity studies upon nine species of aquatic insects. Environ. Res. 9: 332.

Collard, J.M. and R.F. Matagne. 1994. Cd^{2+} resistance in wild-type and mutant strains of *Chlamydomonas reinhardtii*. Environ. Exp. Bot. 34(2): 235-244.

Collyard, S.A., G.T. Ankley, R.A. Hoke and T. Goldenstein. 1994. Influence of age on the relative sensitivity of *Hyalella azteca* to diazinon, alkylphenol ethoxylates, copper, cadmium, and zinc. Arch. Environ. Contam. Toxicol. 26: 110-113.

Conway, H.L. 1978. Sorption of arsenic and cadmium and their effects on growth, micronutrient utilization, and photosynthetic pigment composition of *Asterionella formosa*. J. Fish. Res. Board Can. 35: 286.

Cope, W.G., J.G. Wiener and G.J. Atchison. 1994. Hepatic cadmium, metal-binding proteins and bioaccumulation in bluegills exposed to aqueous cadmium. Environ. Toxicol. Chem. 13(4): 553-562.

Coppellotti, O. 1994. Effects of cadmium on *Uronema marinum* (ciliophora, scuticociliatida) from Antarctica. Acta Protozool. 33: 159-167.

Couillard, Y., P. Ross and B. Rinel-Alloul. 1989. Acute toxicity of six metals to the rotifer *Brachionus calyciflorus*, with comparisons to other freshwaer organisms. Toxic. Assess. 4(4): 451-462.

Craig, A., L. Hare, P.M. Charest and A. Tessier. 1998. Effect of exposure regime on the internal distribution of cadmium in *Chironomus staegeri* larvae (insecta, diptera). Aquat. Toxicol. 41: 265-275.

Craig, A., L. Hare and A. Tessier. 1999. Experimental evidence for cadmium uptake via calcium channels in the aquatic insect *Chironomus staegeri*. Aquat. Toxicol. 44: 255-262.

Cripe, G.M. 1994. Comparative acute toxicities of several pesticides and metals to *Mysidopsis bahia* and postlarval *Penaeus duorarum*. Environ. Toxicol. Chem. 13(11): 1867-1872.

Crisinel, A., L. Delaunay, D. Rossel, J. Tarradellas, H. Meyer, H. Saiah, P. Vogel, C. Delisle and C. Blaise. 1994. Cyst-based ecotoxicological tests using anostracans: comparison of two species of *Streptocephalus*. Environ. Toxicol. Water Qual. 9(4): 317-326.

Currie, R.S., D.C.G. Muir, W.L. Fairchild, M.H. Holoka and R.E. Hecky. 1998. Influence of nutrient additions on cadmium bioaccumulation by aquatic invertebrates in littoral enclosures. Environ. Toxicol. Chem. 17(12): 2435-2443.

Cusimano, R.F., D.F. Brakke and G.A. Chapman. 1986. Effects of pH on the toxicities of cadmium, copper, and zinc to steelhead trout (*Salmo gairdneri*). Can. J. Fish. Aquat. Sci. 43: 1497-1503.

D'Agostino, A. and C. Finney. 1974. The effect of copper and cadmium on the development of *Tigriopus japonicus*. *In:* F.J. Vernberg and W.B. Vernberg (eds.), Pollution and Physiology of Marine Organisms. Academic Press, New York. p. 445.

D'Aniello, A., M. Pischetola, F. Vanacore, M. De Nicola and M. Denuce. 1990. Effect of mercury, cadmium and copper on the development and viability of *Loligo vulgaris* and *Sepia officinalis* embryos. Ital. J. Biochem. 39(2): 130A-132A.

Dallinger, R., E. Carpene, G.J. Dalla Via and P. Cortesi. 1989. Effects of cadmium on *Murex trunculus* from the Adriatic Sea. I. Accumulation of metal and binding to a metallothionein-like protein. Arch. Environ. Contam. Toxicol. 18: 554-561.

Dallinger, R., M. Egg, G. Kock and R. Hofer. 1997. The role of metallothionein in cadmium accumulation of Arctic char (*Salvelinus alpinus*) from high alpine lakes. Aquat. Toxicol. 38: 47-66.

Darmono, D. 1990. Uptake of cadmium and nickel in banana prawn (*Penaeus merguiensis* de Man). Bull. Environ. Contam. Toxicol. 45: 320-328.

Darmono, D., G.R.W. Denton and R.S.F. Campbell. 1990. The pathology of cadmium and nickel toxicity in the banana shrimp (*Penaeus merguiensis* de Man). Asian Fish. Sci. 3(3): 287-297.

Datta, D.K and G.M. Sinha. 1987. Estimation of acute toxicity of cadmium, a heavy metal, in a carnivorous freshwater teleost, *Mystus vittatus* (Bloch). *In*: Proc. Indian Natl. Sci. Acad. Part B 53(1): 43-45.

Dave, G., et al. 1981. Toxicity of eight solvent extraction chemicals and of cadmium to water fleas, *Daphnia magna*, rainbow trout, *Salmo gairdneri*, and zebrafish, *Brachydanio rerio*. Comp. Biochem. Physiol. 69C: 83.

Davies, I.M., et al. 1981. Field and experimental studies on cadmium in the edible crab *Cancer pagurus*. Mar. Biol. 64: 291.

Davies, N.A., M.G. Taylor and K. Simkiss. 1997. The influence of particle surface characteristics on pollutant metal uptake by cells. Environ. Pollut. 96(2): 179-184.

Davies, P.H. 1976. Use of dialysis tubing in defining the toxic fractions of heavy metals in natural water. *In:* R.W. Andrew, et al. (eds.), Toxicity to Biota of Metal Forms in Natural Water. International Joint Commission, Windsor, Ontario. p. 110.

Davies, P.H. and W.C. Gorman. 1987. Effects of chemical equilibria and kinetics on the bioavailability and toxicity of cadmium to rainbow trout. Am. Chem. Soc. Natl. Meeting. 194: 646-650.

Davies, P.H., W.C. Gorman, C.A. Carlson and S.F. Brinkman. 1993. Effect of hardness on bioavailability and toxicity of cadmium to rainbow trout. Chem. Spec. Bioavail. 5(2): 67-77.

Davies, R.W., R.N. Singhal and D.D. Wicklum. 1995. Changes in reproductive potential of the leech *Nephelopsis obscura* (Erpobdellidae) as biomarkers for cadmium stress. Can. J. Zool. 73: 2192-2196.

Dawson, M.A., et al. 1977. Physiological response of juvenile striped bass, *Morone saxatilis*, to low levels of cadmium and mercury. Chesapeake Sci. 18: 353.

De Conto Cinier, C., M. Petit-Ramel, R. Faure and D. Garin. 1997. Cadmium bioaccumulation in carp (*Cyprinus carpio*) tissues during long-term high exposure: analysis by inductively coupled plasma-mass spectrometry. Ecotoxicol. Environ. Safety. 38: 137-143.

De Conto Cinier, C, M. Petit-Ramel, R. Faure and M. Bortolato. 1998. Cadmium accumulation and metallothionein biosynthesis in *Cyprinus carpio* tissues. Bull. Environ. Contam. Toxicol. 61: 793-799.

De Lisle, P.F. and M.H. Roberts, Jr. 1988. The effect of salinity on cadmium toxicity to the estuarine mysid *Mysidopsis bahia*: role of chemical speciation. Aquat. Toxicol. 12: 357-370.

De Lisle, P.F. and M.H. Roberts, Jr. 1994. The effect of salinity on cadmium toxicity in the estuarine mysid *Mysidopsis bahia*: roles of osmoregulation and calcium. Mar. Environ. Res. 37: 47-62.

De March, B.G.E. 1988. Acute toxicity of binary mixtures of five cations (Cu^{2+}, Cd^{2+}, Zn^{2+}, Mg^{2+} and K^{+}) to the freshwater amphipod *Gammarus lacustris* (Sars): alternative descriptive models. Can. J. Fish. Aquat. Sci. 45: 625-633.

De Nicola Giudici, M. and S.M. Guarino. 1989. Effects of chronic exposure to cadmium or copper on *Idothea baltica* (crustacea, isopoda). Mar. Pollut. Bull. 20(2): 69-73.

De Nicloa Guidici, M. and L. Migliore. 1988. Long term effect of cadmium of copper on *Asellus aquaticus* (L.) (Crustacea, isopoda). Verh.- Int. Ver. Theor. Angew. Limnol. 23: 1660-1662.

De Nicola, M., N. Cardellicchio, C. Gambardella, S.M. Guarino and C. Marra. 1993. Effects of cadmium on survival, bioaccumulation, histopathology, and PGM polymorphism in the marine isopod *Idotea baltica*. Ecotoxicol. Met. Invert. Proc. Sess. 1993. 1st Meet.: 103-116.

Debelak, R.W. 1975. Acute toxicity of mixtures of copper, chromium, and cadmium to *Daphnia magna*. Thesis. Miami University, Oxford, Ohio.

Decho, A.W. and S.N. Luoma. 1994. Humic and fulvic acids: ink or source in the availability of metals to the marine bivalves *Macoma balthica* and *Potamocorbula amurensis*? Mar. Ecol. Prog. Ser. 108: 133-145.

DeFilippis, L.F., et al. 1981. The effects of sublethal concentrations of zinc, cadmium and mercury on *Euglena*. II. respiration, photosynthesis and photochemical activities. Arch. Microbiol. 128: 407.

Del Ramo, J, J. Diaz-Mayans, A. Torreblanca and A. Nunez. 1987. Effects of temperature on the acute toxicity of heavy metals (Cr, Cd, and Hg) to the freshwater crayfish, *Procambarus clarkii* (Girard). Bull. Environ. Contam. Toxicol. 38: 736-741.

Demon, A., M. De Bruin and H. Wolterbeek. 1988. The influence of pH on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*). Environ. Monit. Assess. 10-2: 165-173.

Demon, A., M. De Bruin and H. Wolterbeek. 1989. The influence of pre-treatment, temperature and calcium ions on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*). Environ. Monit. Assess. 13: 21-33.

Den Besten, P.J., H.J. Herwig, D.I. Zandee and P.A. Voogt. 1989. Effects of cadmium and PCBs on reproduction of the sea star *Asterias rubens*: aberrations in the early development. Ecotoxicol. Environ. Safety. 18(2): 173-180.

Den Besten, P.J., E.G. van Donselaar, H.J. Herwig, D.I. Zandee and P.A. Voogt. 1991. Effects of cadmium on gametogenesis in the sea star *Asterias rubens* L. Aquat. Toxicol. 20: 83-94.

Denton, G.R.W. and C. Burdon-Jones. 1981. Influence of temperature and salinity on the uptake, distribution, and depuration of mercury, cadmium, and lead by the black-lip oyster *Saccostrea echinata*. Mar. Biol. 64: 317.

Denton, G.R.W. and C. Burdon-Jones. 1986. Environmental effects on toxicity of heavy metals to two species of tropical marine fish from northern Australia. Chem. Ecol. 2: 233-249.

Department of the Environment. 1973. Water Pollut. Res. 1972. London. p. 37.

Devi, M., D.A. Thomas, J.T. Barber and M. Fingerman. 1996. Accumulation and physiological and biochemical effects of cadmium in a simple aquatic food chain. Ecotoxicol. Environ. Safety. 33: 38-43.

Devi, V.U. 1987. Heavy metal toxicity to fiddler crabs, *Uca annulipes* Latreille and *Uca triangularis* (Milne Edwards): tolerance to copper, mercury, cadmium, and zinc. Bull. Environ. Contam. Toxicol. 39: 1020-1027.

Devi, V.U. 1996. Bioaccumulation and metabolic effects of cadmium on marine fouling dressinid bivalve, *Mytilopsis sallei* (Recluz). Arch. Environ. Contam. Toxicol. 31: 47-53.

Devi, V.U. and Y.P. Rao. 1989. Cadmium accumulation in fiddler crabs *Uca annulipes* latelle and *Uca triangularis* (Milne Edwards). Water, Air, Soil Pollut. 43: 309-321.

Devi Prasad, P.V. and P.S. Devi Prasad. 1982. Effect of cadmium, lead and nickel on three freshwater green algae. Water Air, Soil Pollut. 17: 263.

Devineau, J. and C.A. Triquet. 1985. Patterns of bioaccumulation of an essential trace element (zinc) and a pollutant metal (cadmium) in larvae of the prawn *Palaemon serratus*. Mar. Biol. 86: 139-143.

Di Giulio, R.T. and R.F. Scanlon. 1984. Sublethal effects of cadmium ingestion on mallard ducks. Arch. Environ. Contam. Toxicol. 13: 765.

Diamond, J.M., D.E. Koplish, J. McMahon III and R. Rost. 1997. Evaluation of the water-effect ratio procedure for metals in a riverine system. Environ. Toxicol. Chem. 16(3): 509-520.

Dickson, G.W., et al. 1982. The effect of chronic cadmium exposure on phosphoadenylate concentrations and adenylate energy charge of gills and dorsal muscle tissue of crayfish. Environ. Toxicol. Chem. 1: 147.

Dierickx, P.J. and E. Bredael-Rozen. 1996. Correlation between the *in vitro* cytotoxicity of inorganic metal compounds to cultured fathead minnow fish cells and the toxicity to *Daphnia magna*. Bull. Environ. Contam. Toxicol. 57: 107-110.

Dillon, T.M. and B.C. Suedel. 1986. The relationship between cadmium bioaccumulation and survival, growth, and reproduction in the freshwater crustacean, *Daphnia magna*. Environ. Contam., 2nd Conf., CEP Consult., Edinburgh, U.K.: 21-23.

Dinnel, P.A., J.M. Link, Q.J. Stober, M.W. Letourneau and W.E. Roberts. 1989. Comparative sensitivity of sea urchin sperm bioassays to metals and pesticides. Arch. Environ. Contam. Toxicol. 18: 748-755.

Dive, D., S. Robert, E. Angrand, C. Bel, H. Bonnemain, L. Brun, Y. Demarque, A. Le Du, R. El Bouhouti, M.N. Fourmaux, L. Guery, O. Hanssens and M. Murat. 1989. A bioassay using the measurement of the growth inhibition of a ciliate protozoan: *Colpidium campylum* Stokes. Hydrobiol. 188/189: 181-188.

Dixon, W.J. and M.B. Brown, eds. 1979. BMDP Biomedical Computer Programs, P-series. University of California, Berkeley, California. p. 521.

Domal-Kwiatkowska, D., B. Sosak-Swiderska, U. Mazurek and D. Tyrawska. 1994. The effect of cadmium on the survival and filtering rate of *Daphnia magna*, Straus 1820. Pol. Arch. Hydrobiol. 41(4): 465-473.

Dorfman, D. 1977. Tolerance of *Fundulus heteroclitus* to different metals in salt waters. Bull. New Jersey Acad. Sci. 22: 21.

Dorgelo, J., H. Meester and C. van Velzen. 1995. Effects of diet and heavy metals on growth rate and fertility in the deposit-feeding snail *Potamopyrgus jenkinsi* (Smith) (Gastropoda: Hydrobiidae). Hydrobiol. 316: 199-210.

Douben, P.E.T. 1989. Uptake and elimination of waterborne cadmium by the fish *Noemacheilus barbatulus* L. (Stone Loach). Arch. Environ. Contam. Toxicol. 18: 576-586.

Drbal, K., K. Veber and J. Zahradnik. 1985. Toxicity and accumulation of copper and cadmium in the alga *Scenedesmus obliquus* LH. Bull. Environ. Contam. Toxicol. 34: 904-908.

Dressing, et al. 1982. Effect of chemical speciation on the accumulation of cadmium by the caddisfly, *Hydropsyche* sp. Bull. Environ. Contam. Toxicol. 28: 172.

Drummond, R.A. and D.A. Benoit. Manuscript. Toxicity of cadmium to fish: some observations on the influence of experimental procedures. U.S. EPA, Duluth, Minnesota.

Duncan, D.A. and J.F. Klaverkamp. 1983. Tolerance and resistance to cadmium in white suckers (*Catostomus commersoni*) previously exposed to cadmium, mercury, zinc, or selenium. Can. J. Fish. Aquat. Sci. 40: 128.

Duquesne, S.J. and J.C. Coll. 1995. Metal accumulation in the clam *Tridacna crocea* under natural and experimental conditions. Aquat. Toxicol. 32: 239-253.

Dyer, S.D., S.E. Belanger and G.J. Carr. 1997. An initial evaluation of the use of Euro/North American fish species for tropical effects assessments. Chemosphere. 35(11): 2767-2781.

Eaton, J.G. 1974. Chronic cadmium toxicity to the bluegill (*Lepomis macrochirus* Rafinesque). Trans. Am. Fish. Soc. 4: 729.

Eaton, J.G. 1980. Memorandum to C.E. Stephan. U.S. EPA, Duluth, Minnesota. August 5.

Eaton, J.G., et al. 1978. Metal toxicity to embryos and larvae of seven freshwater fish species-I. cadmium. Bull. Environ. Contam. Toxicol. 19: 95.

Eisler, R. 1971. Cadmium poisoning in *Fundulus heteroclitus* (Pisces: Cyprinodontidae) and other marine organisms. J. Fish. Res. Board Can. 28: 1225.

Eisler, R. 1974. Radio cadmium exchange with seawater by *Fundulus heteroclitus* (L.) (Pisces: Cyprinodontidae). J. Fish Biol. 6: 601.

Eisler, R. 1977. Acute toxicities of selected heavy metals to the soft-shell clam, *Mya arenaria*. Bull. Environ. Contam. Toxicol. 17: 137.

Eisler, R. 1981. Trace Metal Concentrations in Marine Organisms. Pergamon Press, New York.

Eisler, R. and G.R. Gardner. 1973. Acute toxicology to an estuarine teleost of mixtures of cadmium, copper, and zinc salts. J. Fish Biol. 5: 131.

Eisler, R. and R. Hennekey. 1977. Acute toxicities of Cd^{+2}, Cr^{+6}, Hg^{+2}, Ni^{+2}, and Zn^{+2} to estuarine macrofauna. Arch. Environ. Contam. Toxicol. 6: 315.

Eisler, R., et al. 1972. Cadmium uptake by marine organisms. J. Fish. Res. Board Can. 29: 1367.

Eisler, R., et al. 1979. Fourth annotated bibliography on biological effects of metals in aquatic environments. EPA-600/3-79-084. National Technical Information Service, Springfield, Virginia.

Elliott, N.G., R. Swain and D.A. Ritz. 1985. The influence of cyclic exposure on the accumulation of heavy metals by *Mytilus edulis planulatus* (Lamarck). Mar. Environ. Res. 15: 17-30.

Elliott, N.G., R. Swain and D.A. Ritz. 1986. Metal interaction during accumulation by the mussel *Mytilus edulis planulatus*. Mar. Biol. 395-399.

Elnabarawy, M.T., A.N. Welter and R.R. Robideau. 1986. Relative sensitivity of three daphnid species to selected organic and inorganic chemicals. Environ. Toxicol. Chem. 5: 393-398.

Engel, D.W. 1999. Accumulation and cytosolic partitioning of metals in the american oyster *Crassostrea virginica*. Mar. Environ. Res. 47: 89-102.

Enserink, L., W. Luttmer and H. Maas-Diepeveen. 1990. Reproductive strategy of *Daphnia magna* affects the sensitivity of its progeny in acute toxicity tests. Aquat. Toxicol. 17: 15-26.

Enserink, L., J.L. Maas-Diepeveen and C.J. Van Leeuwen. 1991. Combined effects of metals; an ecotoxicological evaluation. Water Res. 25(6): 679-687.

Enserink, L., M. De la Haye and H. Maas. 1993. Reproductive strategy of *Daphnia magna*: implications for chronic toxicity test. Aquat Toxicol. 25: 111-124.

Errecalde, O., M. Seidl and P.G.C. Campbell. 1998. Influence of a low molecular weight metabolite (citrate) on the toxicity of cadmium and zinc to the unicellular green alga *Selenastrum capricornutum*: and exception to the free-ion model. Water Res. 32(2): 419-429.

Evans, D.H. 1987. The fish gill: site of action and model for toxic effects of environmental pollutants. Enniron. Health Perspect. 71:47-58.

Everaarts, J.M. 1990. Uptake and release of cadmium in various organs of the common mussel, *Mytilus edulis* (L.). Bull. Environ. Contam. Toxicol. 45: 560-567.

Evtushenko, Z.S., N.N. Belcheva, O.N. Lukyanova. 1986. Cadmium accumulation in organs of the scallop *Mizuhopecten yessoensis* - I. activities of phosphatases and composition and amount of lipids. Comp. Biochem. Physiol. 83C: 371-376.

Evtushenko, Z.S., O.N. Lukyanova and N.N. Belcheva. 1990. Cadmium bioaccumulation in organs of the scallop *Mizuhopecten yessoensis*. Mar. Biol. 104: 247-250.

Fair, P.A. and L.V. Sick. 1983. Accumulations of naphthalene and cadmium after simultaneous ingestion by the Black Sea Bass, *Centropristis striata*. Arch. Environ. Contam. Toxicol. 12: 551.

Faraday, W.E. and A.C. Churchill. 1979. Uptake of cadmium by the eelgrass *Zostera marina*. Mar. Biol. 53: 293.

Farag, A.M., C.J. Boese, D.F. Woodward and H.L. Bergman. 1994. Physiological changes and tissue metal accumulation in rainbow trout exposed to foodborne and waterborne metals. Environ. Toxicol. Chem. 13(12): 2021-2029.

Farag, A.M., D.F. Woodward, J.N. Goldstein, W. Brumbaugh and J.S. Meyer. 1998. Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho. Arch. Environ. Contam. Toxicol. 34: 19-127.

Fargasova, A. 1993. Effect of five toxic metals on the alga *Scenedesmus quadricauda*. Biologia, Bratislava. 48(3): 301-304.

Fargasova, A. 1994a. Toxicity of metals on *Daphnia magna* and *Tubifex tubifex*. Ecotoxicol Environ. Safety. 27: 210-213.

Fargasova, A. 1994b. Comparative toxicity of five metals on various biological subjects. Bull. Environ. Contam. Toxicol. 53: 317-324.

Fennikoh, K.B., et al. 1978. Cadmium toxicity in planktonic organisms of a freshwater food web. Environ. Res. 15: 357.

Fernandez-Leborans, G. and M.T. Antonio-Garcia. 1988. Effects of lead and cadmium in a community of protozoans. Acta Protozool. 27(2): 141-159.

Fernandez-Leborans, G. and A. Novillo-Villajos. 1993. Changes in trophic structure of a freshwater protozoan community subjected to cadmium. Ecotoxicol. Environ. Safety. 25: 271-279.

Fernandez-Leborans, G. and A. Novillo. 1996. Toxicity and bioaccumulation of cadmium in *Olisthodiscus Leteus*. Water Res. 30(1): 57-62.

Fernandez-Pinas, F, P. Mateo and I. Bonilla. 1995. Cadmium toxicity in *Nostoc* UAM208: protection by calcium. New Phytol. 131: 403-407.

Ferrari, L, A. Salibian and C.V. Muino. 1993. Selective protection of temperature against cadmium acute toxicity to *Bufo arenarum* tadpoles. Bull. Environ. Contam. Toxicol. 50: 212-218.

Findlay, D.L., S.E.M. Kasian and E.U. Schindler. 1996. Long-term effects of low cadmium concentrations on a natural phytoplankton community. Can. J. Fish. Aquat. Sci. 53: 1903-1912.

Finlayson, B.J. and K.M. Verrue. 1982. Toxicities of copper, zinc and cadmium mixtures to juvenile chinook salmon. Trans. Am. Fish. Soc. 111: 645-650.

Fisher, N.S. and J.G. Fabris. 1982. Complexation of Cu, Zn and Cd by metabolites excreted from marine diatoms. Mar. Chem. 11: 245.

Fisher, N.S. and G.J. Jones. 1981. Heavy metals and marine phytoplankton: correlation of toxicity and sulfhydryl-binding. J. Phycol. 17: 108.

Fisher, N.S., J.L. Teyssie, S.W. Fowler and W.X. Wang. 1996. Accumulation and retention of metals in mussels from food and water: a comparison under field and laboratory conditions. Environ. Sci. Technol. 30(11): 3232-3242.

Flick, D.F., H.F. Kraybill and J.M. Dimitroff. 1971. Toxic effects of cadmium: a review. Environ. Res. 4: 71-85.

Friberg, L., M. Piscator and G. Nordberg. 1971. Cadmium in the environment. CRC Press. Cleveland, OH. 168 pp.

Florence, T.M., G.M. Morrison and J.L. Stauber. 1992. Determination of trace element speciation and the role of speciation in aquatic toxicity. Sci. Total Environ. 125: 1-13.

Forbes, V.E. 1991. Response of *Hydrobia ventrosa* (Montagu) to environmental stress: effects of salinity fluctuations and cadmium exposure on growth. Funct. Ecol. 5(5): 642-648.

Forget, J., J.F. Pavillon, M.R. Menasria and G. Bocquene. 1998. Mortality and LC50 values for several stages of the marine copepod *Tigriopus brevicornis* (Muller) exposed to the metals arsenic and cadmium and the pesticides atrazine, carbofuran, dichlorvos, and malathion. Ecotoxicol. Environ. Safety. 40: 239-244.

Foster, P.L. 1982. Metal resistances of chlorophyta from rivers polluted by heavy metals. Freshwater Biol. 12: 41.

Francesconi, D.A. 1989. Distribution of cadmium in the pearl oyster, *Pinctada albina albina* (Lamarck), following exposure to cadmium in seawater. Bull. Environ. Contam. Toxicol. 43: 321-328.

Francesconi, K.A., E.J. Moore, J.S. Edmonds. 1994. Cadmium uptake from seawater and food by the western rock lobster *Panulirus cygnus*. Bull. Environ. Contam. Toxicol. 53: 219-223.

Frank, P.M. and P.B. Robertson. 1979. The influence of salinity on toxicity of cadmium and chromium to the blue crab, *Callinectes sapidus*. Bull. Environ. Contam. Toxicol. 21: 74.

Frazier, J.M. 1979. Bioaccumulation of cadmium in marine organisms. Environ. Health Perspect. 28: 75.

Frazier, J.M. and S.G. George. 1983. Cadmium kinetics in oyster - a comparative study of *Crassostrea gigas* and *Ostrea edulis*. Mar. Biol. 76: 55.

Freeman, B.J. 1978. Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress. SRO-757-6. National Technical Information Service, Springfield, Virginia.

Freeman, B.J. 1980. Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress. Thesis. University of Georgia, Athens, Georgia.

Gadkari, A.S. and V.B. Marathe. 1983. Toxicity of cadmium and lead to a fish and a snail from two different habitats. IAWPC Tech. Annual. X: 141-148.

Gaikwad, S.A. 1989. Effects of mixture and three individual heavy metals on susceptibility of three freshwater fishes. Pollut. Res. 8(1): 33-35.

Galic, M., L. Sipos and B. Raspor. 1987. Toxicity of cadmium and nitrilotriacetic acid in sea water to the photobacteria *Vibrio fisheri*. Sci. Total Environ. 60: 173-184.

Gargiulo, G., P. De Girolamo, L. Ferrara, O. Soppelsa, G. Andreozzi, R. Antonucci and P. Battaglini. 1996. Action of cadmium on the gills of *Carassius auratus* L. in the presence of catabolic NH_3. Arch. Environ. Contam. Toxicol. 30: 235-240.

Garofano, J.S. 1979. The effects of cadmium on the peripheral blood and head kidney of the brown bullhead *Ictalurus nebulosus* (Lesueur). Thesis. New York University.

Gaur, J.P., N. Noraho, Y.S. Chauhan. 1994. Relationship between heavy metal accumulation and toxicity in *Spirodela polyrhiza* (L.) Schleid. and *Azolla pinnata* R. Br. Aquat. Bot. 49(2/3): 183-192.

Gentile, J.H. and M. Johnson. 1982. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Gentile, S.M. 1982. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Gentile, S.M., et al. 1982. Chronic effects of cadmium on two species of mysid shrimp: *Mysidopsis bahia* and *Mysidopsis bigelowi*. Hydrobiol. 93: 195.

George, S.G. and T.L. Coombs. 1977. The effects of chelating agents on the uptake and accumulation of cadmium by *Mytilus edulis*. Mar. Biol. 39: 261.

George, S.G., B.J.S. Pirie and J.M. Frazier. 1983. Effects of cadmium exposure on metal-containing amoebocytes of the oyster *Ostrea edulis*. Mar. Biol. 76: 63-66.

Gerhardt, A. 1992. Acute toxicity of Cd in stream invertebrates in relation to pH and test design. Hydrobiol. 239: 93-100.

Gerhardt, A. 1995. Joint and single toxicity of Cd and Fe related to metal uptake in the mayfly *Leptophlebia marginata* (L.) (Insecta). Hydrobiol. 306: 229-240.

Ghosh, A.R. and P. Chakrabarti. 1990. Toxicity of arsenic and cadmium to a freshwater fish. Environ. Ecol. 8(2): 576-579.

Ghosh, T.K., J.P. Kotangale and K.P. Krishnamoorthi. 1990. Toxicity of selective metals to freshwater algae, ciliated protozoa and planktonic crustaceans. Environ. Ecol. 8(1):356-360.

Giesy, J.P., Jr. 1978. Cadmium inhibition of leaf decomposition in an aquatic microcosm. Chemosphere 6: 467.

Giesy, J.P., Jr., et al. 1977. Effects of naturally occurring aquatic organic fractions on cadmium toxicity to *Simocephalus serrulatus* (Daphnidae) and *Gambusia affinis* (Poeciliidae). Water Res. 11: 1013.

Giesy, J.P., Jr., et al. 1979. Fate and biological effects of cadmium introduced into channel microcosms. EPA-600/3-79-039. National Technical Information Service, Springfield, Virginia.

Giles, M.A. 1988. Accumulation of cadmium by rainbow trout, *Salmo gairdneri*, during extended exposure. Can. J. Fish. Aquat. Sci. 45: 1045-1053.

Gill, T.S. and A. Epple. 1992. Impact of cadmium on the mummichog *Fundulus heteroclitus* and the role of calcium in suppressing heavy metal toxicity. Comp. Biochem. Physiol. 101C(3): 519-523.

Gillespie, R., et al. 1977. Cadmium uptake by the crayfish, *Orconectes propinquus propinquus* (Girard). Environ. Res. 13: 364.

Glubokov, A.I. 1990. Growth of three species of fish during early ontogeny under normal and toxic conditions. Voprosy Ikhtiologii. 30(1): 137-143.

Glynn, A.W. 1996. The concentration dependency of branchial intracellular cadmium distribution and influx in the zebrafish (*Brachydanio rerio*). Aquat. Toxicol. 35: 47-58.

Glynn, A.W., C. Haux and C. Hogstrand. 1992. Chronic toxicity and metabolism of Cd and Zn in juvenile minnows (*Phoxinus phoxinus*) exposed to a Cd and Zn mixture. Can. J. Fish. Aquat. Sci. 49: 2070-2079.

Glynn, A.W., L. Norrgren, A. Mussener. 1994. Differences in uptake of inorganic mercury and cadmium in the gills of the zebrafish, *Brachydanio rerio*. Aquat. Toxicol. 30: 13-26.

Gomot, A. 1997. Dose-dependent effects of cadmium on the growth of snails in toxicity bioassays. Arch. Environ. Contam. Toxicol. 33: 209-216.

Gomot, A. 1998. Toxic effects of cadmium on reproduction, development, and hatching in the freshwater snail *Lymnaea stagnalis* for water quality monitoring. Ecotoxicol. Environ. Safety. 41: 288-297.

Gopal, V. and K.M. Devi. 1991. Influence of nutritional status on the median tolerance limits (LC50) of *Ophiocephalus striatus* for certain heavy metal and pesticide toxicants. Indian. J. Environ. Health. 33: 393-394.

Gordon, M., et al. 1980. *Mytilus californianus* as a bioindicator of trace metal pollution: variability and statistical considerations. Mar. Pollut. Bull. 11: 195.

Gorman, W.C. Jr. and R.K. Skogerboe. 1987. Speciation of cadmium in natural waters and their effect on rainbow trout. Preprint extended abstract, presented before the Division of Environ. Chem., Am. Chem. Soc. , Aug. 30 - Sept. 4, 1987. New Orleans, LA: 664-645.

Gossiaux, D.C., P.F. Landrum and V.N. Tsymbal. 1992. Response of the amphipod *Diporeia* spp. to various stressors: cadmium, salinity, and temperature. J. Great Lakes Res. 18(3): 364-371.

Gottofrey, J. and H. Tjalve. 1991. Axonal transport of cadmium in the olfactory nerve of the pike. Pharmacol. Toxicol. 19: 242-252.

Gottofrey, J., I. Bjorklund and H. Tjalve. 1986. Effect of sodium isopropylxanthate, potassium amylxanthate and sodium diethyldithiocarbamate or the uptake and distribution of cadmium in the brown trout (*Salmo trutta*). Aquat. Toxicol. 12: 171-184.

Gould, E. and J. Karolus. 1974. Physiological response of the cunner, *Tautogolabrus adspersus*, to cadmium. Observations on the biochemistry. NOAA Technical Report SSRF-681, Part V.

Gould, E., et al. 1976. Heart transaminase in the rock crab, *Cancer irroratus*, exposed to cadmium salts. Bull. Environ. Contam. Toxicol. 15: 635.

Govindarajan, S., C.P. Valsaraj, R. Mohan, V. Hariprasad and R. Ramasubramanian. 1993. Toxicity of heavy metals in aquaculture organisms: *Penaeus indicus*, *Perna viridis*, *Artemia salina* and *Skeletonema costatum*. Pollut. Res. 12(3): 187-189.

Graney, R.L., Jr., et al. 1983. Heavy metal indicator potential of the Asiatic clam (*Corbicula fluminea*) in artificial stream systems. Hydrobiol. 102: 81.

Graney, R.L., Jr., D.S. Cherry and J. Cairns Jr. 1984. The influence of substrate, pH, diet and temperature upon cadmium accumulation in the asiatic clam (*Corbicula fluminea*) in laboratory artificial streams. Water Res. 18: 833-842.

Green, A.S., G.T. Chandler and E.R. Blood. 1993. Aqueous-, pore-water and sediment-phase cadmium: toxicity relationships for a meiobenthic copepod. Environ. Toxicol. Chem. 12: 1497-1506.

Green, D.W.J., K.A. Williams and D. Pascoe. 1986. The acute and chronic toxicity of cadmium to different life history stages of the freshwater crustacean *Asellus aquaticus* (L). Arch. Environ. Contam. Toxicol. 15(5): 465-471.

Greenwood, J.G. and D.R. Fielder. 1983. Acute toxicity of zinc and cadmium to zoeae of three species of portnid crabs (Crustacea: Brachyura). Comp. Biochem. Physiol. 75C: 141.

Greig, R.A. 1979. Trace metal uptake by three species of mollusks. Bull. Environ. Contam. Toxicol. 22: 643.

Greig, R.A. and D.R. Wenzloff. 1978. Metal accumulation and depuration by the american oyster, *Crassostrea virginica*. Bull. Environ. Contam. Toxicol. 20: 499.

Guanzon, N.G., Jr., H. Nakahara and Y. Yoshida. 1994. Inhibitory effects of heavy metals on growth and photosynthesis of three freshwater microalgae. Fish. Sci. 60(4): 379-384.

Guerin, J.L. and W.B. Stickle. 1995. Effects of cadmium on survival, osmoregulatory ability and bioenergetics of juvenile blue crabs *Callinectes sapidus* at different salinities. Mar. Environ. Res. 40(3): 227-246.

Guerin, C., N. Giani and M. Sire. 1994. A study of the sensitivity of *Enchytraeus variatus* (Oligochaeta, Enchytraeidae) to certain salts of heavy metals in relation to its use as a test organism. Ann. Limnol. 30(3): 167-178.

Guilhermino, L., M.C. Lopes, A.P. Carvalho and A.M.V.M. Soares. 1996. Inhibition of acetylcholinesterase activity as effect criterion in acute tests with juvenile *Daphnia magna*. Chemosphere. 32(4): 727-738.

Guilhermino, L., T.C. Diamantino, R. Ribeiro, F. Goncalves and A.M.V.M. Soares. 1997. Suitability of test media containing EDTA for the evaluation of acute metal toxicity to *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 38: 292-295.

Gully, J.R. and A.Z. Mason. 1993. Cytosolic redistribution and enhanced accumulation of Cu in gill tissue of *Littorina littorea* as a result of Cd exposure. Mar. Environ. Res. 35: 53-57.

Gupta, A.K. and V.K. Rajbanshi. 1991. Toxicity of copper and cadmium to *Heteropneustes fossilis* (Bloch) Acta Hydrochim. Hydrobiol. 19(3): 331-340.

Gupta, M. and S. Devi. 1995. Uptake and toxicity of cadmium in aquatic ferns. J. Environ. Biol. 16(2): 131-136.

Gupta, M., S. Devi and J. Singh. 1992. Effects of long-term low-dose exposure to cadmium during the entire life cycle of *Ceratopteris thalictroides*, a water fern. Arch. Environ. Contam. Toxicol. 23(2): 184-189.

Hader, D.P., M. Lebert, H. Tahedl and P. Richter. 1997. The Erlanger flagellate test (EFT): photosynthetic flagellates in biological dosimeters. J. Photochem. Photobiol, B: Biol. 40: 23-28.
Haines, T.A. and W.G. Brumaugh. 1994. Metal concentration in the gill, gastrointestinal tract, and carcass of white suckers (*Catostomus commersoni*) in relation to lake acidity. Water, Air, Soil Pollut. 73: 265-274.

Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17: 66.

Hall, L.W., Jr., L.O. Horseman and S. Zeger. 1984. Effects of organic and inorganic chemical contaminants on fertilization, hatching success, and prolarval survival of striped bass. Arch. Environ. Contam. Toxicol. 13: 723-729.

Hall, L.W., Jr., W.S. Hall, S.J. Bushong and R.L. Herman. 1987. *In situ* striped bass (*Morone saxatilis*) contaminant and water quality studies in the Potomac River. Aquat. Toxicol. 19: 73-99.

Hall, L.W., Jr., S.J. Bushong, M.C. Ziegenfuss, W.S. Hall and R.L. Herman. 1988. Concurrent mobile on-site and *in situ* striped bass contaminant and water quality studies in the Choptank River and upper Chesapeake Bay. Environ. Toxicol. Chem. 7: 815-830.

Hall. L.W., Jr., M.C. Ziegenfuss, R.D. Anderson and B.L. Lewis. 1995. The effect of salinity on the acute toxicity of total and free cadmium to a Chesapeake Bay copepod and fish. Mar. Pollut. Bull. 30(6): 376-384.

Hall, W.S., R.L. Paulson, L.W. Hall, Jr. and D.T. Burton. 1986. Acute toxicity of cadmium and sodium pentachlorophenate to daphnids and fish. Bull. Environ. Contam. Toxicol. 37: 308-316.

Ham, L., R. Quinn and D. Pascoe. 1995. Effects of cadmium on the predator-prey interaction between the Turbellarian *Dendrocoelum lacteum* (Muller, 1774) and the isopod crustacean *Asellus aquaticus* (L.). Arch. Environ. Contam. Toxicol. 29: 358-365.

Hamilton, S.J. and K.J. Buhl. 1990. Safety assessment of selected inorganic elements to fry of chinook salmon (*Oncorhynchus tshawytscha*). Ecotoxicol. Environ. Safety. 20: 307-324.

Handy, R.D. 1993. The effect of acute exposure to dietary Cd and Cu organ toxicant concentrations in rainbow trout, *Oncorhynchus mykiss*. Aquat. Toxicol. 27: 1-14.

Hansen, I.V., J.M. Weeks and M.H. Depledge. 1995 Accumulation of copper, zinc, cadmium and chromium by the marine sponge *Halichondria panicea* Pallas and the implications for biomonitoring. Mar. Pollut. Bull. 31(3-1): 133-138.

Hansten, C., M. Heino and K. Pynnonen. 1996. Viability of glochidia of *Anodonta anatina* (Unionidae) exposed to selected metals and chelating agents. Aquat. Toxicol. 34: 1-12.

Hardy, J.K. and D.H. O'Keeffe. 1985. Cadmium uptake by the water hyacinth: effects of root mass, solution volume, complexers and other metal ions. Chemosphere. 14(5): 417-426.

Hardy, J.K. and N.B. Raber. 1985. Zinc uptake by the water hyacinth: effect of solution factors. Chemosphere. 14(9): 1155-1166.

Hare, L. 1992. Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity. Critic. Rev. Toxicol. 22(5/6): 327-369.

Hare, L, E. Saouter, P.G.C. Campbell, A. Tessier, F. Ribeyre and A. Boudou. 1991. Dynamics of cadmium, lead, and zinc exchange between nymphs of the burrowing mayfly *Hexagenia rigida* (Ephemeroptera) and the environment. Can. J. Fish. Aquat. Sci. 48: 39-47.

Hare, L., R. Carignan and M.A. Huerta-Diaz. 1994. A field study of metal toxicity and accumulation by benthic invertebrates; implications for the acid-volatile sulfide (AVS) model. Limnol. Oceanogr. 39(7): 1653-1668.

Haritonidis, S., J.W. Rijstenbil, P. Malea, J. van Drie and J.A. Wijnholds. 1994. Trace metal interactions in the macroalga *Enteromorpha prolifera* (O.F. Muller) grown in water of the Scheldt estuary (Belgium and SW Netherlands), in response to cadmium exposure. BioMetals. 7: 61-66.

Harrison, S.E. and J.F. Klaverkamp. 1989. Uptake, elimination and tissue distribution of dietary and aqueous cadmium by rainbow trout (*Salmo gairdneri* Richardson) and lake whitefish (*Coregonus clupeaformis* Mitchell). Environ. Toxicol. Chem. 8: 87-97.

Hart, B.A. and B.D. Schaife. 1977. Toxicity and bioaccumulation of cadmium in *Chlorella pyrenoidosa*. Environ. Res. 14: 401.

Hartwell, S.I. 1997. Demonstration of a toxicological risk ranking method to correlate measures of ambient toxicity and fish community diversity. Environ. Toxicol. Chem. 16(2): 361-371.

Harvey, R.W. and S.N. Luoma. 1985. Separation of solute and particulate vectors of heavy metal uptake in controlled suspension-feeding experiments with *Macoma balthica*. Hydrobiol. 21: 97-102.

Hashim, M.A., K.H. Chu, S.M. Phang and G.S. Ong. 1997. Adsorption equilibria of cadmium on algal biomass. Adsorpt. Sci. Technol. 15(6): 445-453.

Hatakeyama, S. 1987. Chronic effects of Cd on reproduction of *Polypedilum nubifer* (chironomidae) through water and food. Environ. Pollut. 48: 249-261.

Hatakeyama, S. and M. Yasuno. 1981a. The effects of cadmium-accumulated chlorella on the reproduction of *Moina macrocopa* (Cladocera). Ecotoxicol. Environ. Safety 5: 341.

Hatakeyama, S. and M. Yasuno. 1981b. Effects of cadmium on the periodicity of parturation and brood size of *Moina macrocopa* (Cladocera). Environ. Pollut. (Series A) 26: 111.

Haynes, G.J., A.J. Stewart and B.C. Harvey. 1989. Gender-dependent problems in toxicity tests with *Ceriodaphnia dubia*. Bull. Environ. Contam Toxicol. 43: 271-279.

Hazen, R.E. and T.J. Kneip. 1980. Biogeochemical cycling of cadmium in a marsh ecosystem. *In:* J.O. Nriagu (ed.), Cadmium in the Environment, Part I. Wiley, New York. p. 399.

Heinis, F., K.R. Timmermans and W.R. Swain. 1990. Short-term sublethal effects of cadmium on the filter feeding chironomid larva *Glyptotendipes pallens* (Meigen) (Diptera). Aquat. Toxicol. 16: 73-86.

Hendriks, J.A. 1995. Modelling equilibrium concentrations of microcontaminants in organisms of the Rhine delta: Can average field residues in the aquatic food chain be predicted from laboratory accumulation? Aquat. Toxicol. 31: 1-25.

Henriksen, A. and R.F. Wright. 1978. Concentrations of heavy metals in small Norwegian lakes. Water Res. 12: 101-112.

Herkovits, J. and C.S. Perez-Coll. 1993. Stage-dependent susceptibility of *Bufo arenarum* embryos to cadmium. Bull. Environ. Contam. Toxicol. 50: 608-611.

Herkovits, J. and C.S. Perez-Coll. 1995. Increased resistance against cadmium toxicity by means of pretreatment with low cadmium-zinc concentrations in *Bufo arenarum* embryos. Biol. Trace Elem. Res. 49: 171-175.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1997. Susceptibility of early life stages of *Xenopus laevis* to cadmium. Environ. Toxicol. Chem. 16(2): 312-316.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1998. Cadmium uptake and bioaccumulation in *Xenopus laevis* embryos at different developmental stages. Ecotoxicol. Environ. Safety. 39: 21-26.

Herwig, H.J., F. Brands, E. Kruitwagen and D.I. Zandee. 1989. Bioaccumulation and histochemical localization of cadmium in *Dreissena polymorpha* exposed to cadmium chloride. Aquat. Toxicol. 15: 269-286.

Heumann, H.G. 1987. Effects of heavy metals on growth and ultrastructure of *Chara vulgaris*. Protoplasma. 136: 37-48.

Hickey, C.W. and W.H. Clements. 1998. Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams. Environ. Toxicol. Chem. 17(11): 2338-2346.

Hickey, C.W. and M.L. Martin. 1995. Relative sensitivity of five benthic invertebrate species to reference toxicants and resin-acid contaminated sediments. Environ. Toxicol. Chem. 14(8): 1401-1409.

Hickey, C.W. and D.S. Roper. 1992. Acute toxicity of cadmium to two species of infaunal marine amphipods (tube-dwelling and burrowing) from New Zealand. Bull. Environ. Contam. Toxicol. 49: 165-170.

Hickey, C.W. and M.L. Vickers. 1992. Comparison of the sensitivity to heavy metals and pentachlorophenol of the mayflies *Deleatidium* spp. and the cladoceran *Daphnia magna*. New Zealand J. Mar. Freshwater Res. 26: 87-93.

Hilmy, A.M., M.B. Shabana and A.Y. Daabees. 1985. Bioaccumulation of cadmium: toxicity in *Mugil cephalus*. Comp. Biochem. Physiol. 81(1): 139-143.

Hiraoka, Y. 1985. Acute toxicity of 14 different kinds of metals affecting medaka (*Oryzias latipes*) fry. Hiroshima J. Med. Sci. 34: 327-30.

Hockett, J. R and D.R. Mount. 1996. Use of metal chelating agents to differentiate among sources of acute aquatic toxicity. Environ. Toxicol. Chem. 15: 1687-1693.

Hofslagare, O., G. Samuelsson and S. Sjoberg. 1985. Cadmium effects on photosynthesis and nitrate assimilation in *Scenedesmus obliquus*. A potentiometric study in an open CO_2-system. Environ. Exp. Bot. 25(1): 75-82.

Hogstrand, C., L. Goran and C. Haux. 1991. The importance of metallothionein for the accumulation of copper, zinc and cadmium in environmentally exposed perch, *Perca fluviatilis*. Pharmacol. Toxicol. 68: 492-501.

Holcombe, G.W., et al. 1983. Toxicity of selected priority pollutants to various aquatic organisms. Ecotoxicol. Environ. Safety 7: 400.

Holcombe, G.W., et al. 1984. Methods for conducting snail (*Aplexa hypnorum*) embryo through adult exposures: effects of cadmium and reduced pH levels. Arch. Environ. Contam. Toxicol. 13: 627.

Hollibaugh, D.L., et al. 1980. A comparison of the acute toxicities of ten heavy metals to the plankton from Sasnick Inlet, B.C., Canada. Estuarine Coastal Mar. Sci. 10: 93.

Hollis, L, K. Burnison and R.C. Playle. 1996. Does the age of metal-dissolved organic carbon complexes influence binding of metals to fish gills? Aquat. Toxicol. 35: 253-264.

Hollis, L., L. Muench and R.C. Playle. 1997. Influence of dissolved organic matter on copper binding, and calcium on cadmium binding by gills of rainbow trout. J. Fish Biol. 50: 703-720.

Hong, J.S. and D.J. Reish. 1987. Acute toxicity of cadmium to eight species of marine amphipod and isopod crustaceans from southern California. Bull. Environ. Contam. Toxicol. 39: 884-888.

Hooten, R.L. and R.S. Carr. 1997. Development and application of a marine sediment pore-water toxicity test using *Ulva fasciata* zoospores. Environ. Toxicol. Chem. 17(5): 932-940.

Hornstrom, E. 1990. Toxicity test with algae - a discussion on the batch method. Ecotoxicol. Environ. Safety. 20: 343-353.

Hu, S., C.H. Tang and M. Wu. 1996. Cadmium accumulation by several seaweeds. Sci. Total Environ. 187: 65-71.

Huebert, D.B. and J.M. Shay. 1991. The effect of cadmium and its interaction with external calcium in the submerged aquatic macrophyte *Lemna trisulca* L. Aquat. Toxicol. 20: 57-72.

Huebert, D.B. and J.M. Shay. 1992. Zinc toxicity and its interaction with cadmium in the submerged aquatic macrophyte *Lemna trisulca* L. Environ. Toxicol. Chem. 11: 715-720.

Huebert, D.B. and J.M. Shay. 1993. The response of *Lemna trisulca* L. to cadmium. Environ. Pollut. 80: 247-253.

Huebert, D.B., B.S. Dyck and J.M. Shay. 1993. The effect of EDTA on the assessment of Cu toxicity in the submerged aquatic macrophyte, *Lemna trisulca* L. Aquat. Toxicol. 24: 183-194.

Huebner, J.D. and K.S. Pynnonen. 1992. Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals. Can. J. Zool. 70: 2348-2355.

Hughes, G.M., et al. 1979. A morphometric study of effects of nickel, chromium and cadmium on the secondary lamellae of rainbow trout gills. Water Res. 13: 665.

Hughes, J.S. 1973. Acute toxicity to thirty chemicals to striped bass (*Morone saxatilis*). Western Assoc. State Game Fish Comm., Salt Lake City, Utah. July.

Hung, Y. 1982. Effects of temperature and chelating agents on cadmium uptake in the American oyster. Bull. Environ. Contam. Toxicol. 28: 546.

Husaini, Y., A.K. Singh and L.C. Rai. 1991. Cadmium toxicity to photosynthesis and associated electron transport system of *Nostoc linckia*. Bull. Environ. Contam. Toxicol. 46: 146-150.

Hutcheson, M.S. 1975. The effects of temperature and salinity on cadmium uptake by the blue crab, *Callinectes sapidus*. Chesapeake Sci. 15: 237.

Hutchinson, T.C. and H. Czyrska. 1972. Cadmium and zinc toxicity and synergism to floating aquatic plants. *In:* Water Pollut. Res. in Canada 1972. Proc. 7th Canadian Symp. Water Pollut. Res., Inst. Environ. Sci. Eng. Publ. No. EI-3. p. 59.

Hutchinson, T.C. and P.M. Stokes. 1975. Heavy metal toxicity and algal bioassays. *In:* S. Barabos (ed.), Water Quality Parameters. ASTM STP 573. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 320.

Hutchinson, T.H., T.D. Williams and G.J. Eales. 1994. Toxicity of cadmium, hexavalent chromium and copper to marine fish larvae (*Cyprinodon variegatus*) and copepods (*Tisbe battagliai*). Mar. Environ. Res. 38: 275-290.

Hutton, M. 1983. Sources of cadmium in the environment. Ecotoxicol. Environ. Safety. 7: 9-24.

Hwang, P.P., S.W. Lin and H.C. Lin. 1995. Different sensitivities to cadmium in Tilapia larvae (*Oreochromis mossambicus*; Teleostei). Arch. Environ. Contam. Toxicol. 29:1-7.

Hylland, K., M. Skold, J.S. Gunnarsson and J. Skei. 1997. Interactions between eutrophication and contaminants. IV. Effects on sediment-dwelling organisms. Mar. Pollut. Bull. 33(1-6): 90-99

Iftode, F., J.J. Curgy, A. Fleury and G. Fryd-Versavel. 1985. Action of a heavy ion, Cd^{2+}, and the antagonistic effect of Ca^{2+}, on two ciliates *Tetrahymena pyriformis* and *Euplotes vannus*. Acta Protozool. 24(3-4): 273-279.

Ikuta, K. 1987. Cadmium accumulation by a top shell *Batillus cornutus*. Nippon Suisan Gakkaishi. 53(7): 1237-1242.

Ilangovan, K., R.O. Canizares-Villanueva, S. Gonzalez Moreno and D. Voltolina. 1998. Effect of cadmium and zinc on respiration and photosynthesis in suspended and immobilized cultures of *Chlorella vulgaris* and *Scenedesmus acutus*. Bull. Environ. Contam. Toxicol. 60: 936-943.

Ingersoll, C.G. and N. Kemble. 2000. Unpublished. Methods development for long-term sediment toxicity tests with the amphipod *Hyalella azteca* and the midge *Chironomus tentans*.

Ingersoll, C.G. and R.W. Winner. 1982. Effect on *Daphnia pulex* (De Geer) of daily pulse exposures to copper or cadmium. Environ. Toxicol. Chem. 1: 321.

Inza, B., F. Ribeyre and A. Boudou. 1998. Dynamics of cadmium and mercury compounds (inorganic mercury or methylmercury): uptake and depuration in *Corbicula fluminea*. Effects of temperature and pH. Aquat. Toxicol. 43: 273-285.

Irato, P. and Piccinni, E. 1996. Effects of cadmium and copper on *Astasia longa*: metal uptake and glutathione levels. Acta Protozool. 35: 281-285.

Issa, A.A., R. Abdel-Basset and M.S. Adam. 1995. Abolition of heavy metal toxicity on *Kirchneriella lunaris* (Chlorophyta) by calcium. Ann. Bot. 75: 189-192.

Jak, R.G., J.L. Maas and M.C.T. Scholten. 1996. Evaluation of laboratory derived toxic effect concentrations of a mixture of metals by testing freshwater plankton communities in enclosure. Water Res. 30(5): 1215-1227.

Jana, S. and S.S. Sahana. 1988. Effects of copper, cadmium and chromium cations on the freshwater fish *Clarias batrachus* L. Physiol. Bohemoslov. 37(1): 79-82.

Jana, S. and S.S. Sahana. 1989. Sensitivity of the freshwater fishes *Clarias batrachus* and *Anabas testudineus* to heavy metals. Environ. Ecol. 7(2): 265-270.

Janssen, C.R. and G. Persoone. 1993. Rapid toxicity screening tests for aquatic biota. I. Methodology and experiments with *Daphnia magna*. Environ. Toxicol. Chem. 12:711-717.

Janssen, H.H. and N. Scholz. 1979. Uptake and cellular distribution of cadmium in *Mytilus edulis*. Mar. Biol. 55: 133.

Janssen, M.P.M., C. Oosterhoff, G.J.S.M. Heijmans and H. Van der Voet. 1995. The toxicity of metal salts and the population growth of the Ciliate *Colpoda cucculus*. Bull. Environ. Contam. Toxicol. 54: 597-605.

Janssens de Bisthoven, L.G., K.R. Timmerans and F. Ollevier. 1992. The concentration of cadmium, lead, copper and zinc in *Chironomus thummi* larvae (Diptera, chironomidae) with deformed versus normal menta. Hydrobiol. 239: 141-149.

Jarvinen, A.W. and G.T. Ankley. 1999. Linkage of effects to tissue residues: development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. Society of Environmental Toxicology and Chemistry. Pensacola, FL. 364 pp.

Jaworska, M., A. Gorczyca, J. Sepiol and P. Tomasik. 1997. Effect of metal ions on the entomopathogenic nematode *Heterorhabditis bacteriophora poinar* (Nematoda: Heterohabditidae) under laboratory conditions. Water, Air, Soil Pollut. 93: 157-166.

Jenkins, K.D. and A.Z. Mason. 1988. Relationships between subcellular distributions of cadmium and perturbations in reproduction in the polychaete *Neanthes arenaceodentata*. Aquat. Toxicol. 12: 229-244.

Jenkins, K.D. and B.M. Sanders. 1986. Relationships between free cadmium ion activity in seawater, cadmium accumulation and subcellular distibution, and growth in polychaetes. Environ. Health Perspect. 65: 205-210.

Jenner, H.A. and J.P.M. Janssen-Mommen. 1993. Duckweed *Lemna minor* as a tool for testing toxicity of coal residues and polluted sediments. Arch. Environ. Contam. Toxicol. 25: 3-11.

Jennings, J.R. and P.S. Rainbow. 1979a. Studies on the uptake of cadmium by the crab *Carcinus maenas* in the laboratory. I. Accumulation from seawater and a food source. Mar. Biol. 50: 131.

Jennings, J.R. and P.S. Rainbow. 1979b. Accumulation of cadmium by *Dunaliella tertiolecta* Butcher. J. Plankton Res. 1: 67.

Jindal, R. and A. Verma. 1990. Heavy metal toxicity to *Daphnia pulex*. Indian J. Environ. Hlth. 32(3): 289-292.

John, J., E.T. Gjessing, M. Grande and B. Salbu. 1987. Influence of aquatic humus and pH on the uptake and depuration of cadmium by the Atlantic salmon (*Salmo salar* L.). Sci. Total Environ. 62: 253-265.

Johns, D.M. and D.C. Miller. 1982. The use of bioenergetics to investigate the mechanisms of pollutant toxicity in crustacean larvae. *In:* W.B. Vernberg, et al. (eds.), Physiological Mechanisms of Marine Pollutant Toxicity. Academic Press, New York. p. 261.

Johnson, M. and J. Gentile. 1979. Acute toxicity of cadmium, copper, and mercury to larval American lobster (*Homarus americanus*). Bull. Environ. Contam. Toxicol. 22: 258.

Jones, M.B. 1975. Synergistic effects of salinity, temperature and heavy metals on mortality and osmoregulation in marine and estuarine isopods (Crustacea). Mar. Biol. 30: 13.

Jonnalagadda, S.B. and P.V.V.P. Rao. 1993. Toxicity, bioavailability and metal speciation. Comp. Biochem. Physiol. 106C(3): 585-595.

Jop, K.M. 1991. Concentration of metals in various larval stages of four *Ephemeroptera* species. Bull. Environ. Contam. Toxicol. 46: 901-905.

Jop, K.M., A.M. Askew and R.B. Foster. 1995. Development of a water-effect ratio for copper, cadmium, and lead for the Great Works River in Maine using *Ceriodaphnia dubia* and *Salvelinus fontinalis*. Bull. Environ. Contam. Toxicol. 54: 29-33.

Juchelka, C.M. and T.W. Snell. 1994. Rapid toxicity assessment using rotifer ingestion rate. Arch. Environ. Contam. Toxicol. 26: 549-554.

Jude, D.J. 1973. Sublethal effects of ammonia and cadmium on growth of green sunfish. Ph.D. Thesis. Michigan State University.

Kaplan, D., Y.M. Heimer, A. Abeliovich and P.B. Goldsbrough. 1995. Cadmium toxicity and resistance in *Chlorella* sp. Plant Sci. 109: 129-137.

Karlsson-Norrgren, L. and P. Runn. 1985. Cadmium dynamics in fish: pulse studies with ^{109}Cd in female zebrafish, *Brachydanio rerio*. J. Fish Biol. 27: 571-581.

Kapur, K. and N.A. Yadav. 1982. The effects of certain heavy metal salts on the development of eggs in common carp, *Cyprinus carpio* var. *communis*. Acta Hydrochim. Hydrobiol. 10: 517.

Karez, C.S., S. Bonotto and S. Puiseux-Dao. 1989. Response of the unicellular giant alga *Acetabularia acetabulum* to cadmium toxicity and accumulation. Toxicol. Environ. Chem. 19: 223-232.

Kasuga, S. 1980. Sexual differences of medaka, *Oryzias latipes* in the acute toxicity test of cadmium. Bull. Jap. Soc. Sci. Fish. 46(9): 1073-1076.

Katti, S.R. and A.G. Sathyanesan. 1985. Chronic effects of lead and cadmium on the testis of the catfish *Clarias batrachus*. Environ. Ecol. 3(4): 596-598.

Kay, J., D.G. Thomas, M.W. Brown, A. Cryer, D. Shurben, J.F. deLong.G. Solbe and J.S. Garvey. 1986. Cadmium accumulation and protein binding patterns in tissues of the rainbow trout, *Salmo gairdneri*. Environ. Health Perspect. 65: 133-139.

Keduo, C. L. Yumei and H. Lanying. 1987. Effects os six heavy metals on hatching eggs and survival of larval of marine fish. Oceanol. Limol. Sin. (Haiyang Yu Huzhao). 18(2): 138-144.

Keenan, S. and M.A. Alikhan. 1991. Comparative study of cadmium and lead accumulations in *Cambarus bartoni* (Fab.) (Decapoda, crustacea) from an acidic and a neutral lake. Bull. Environ. Contam. Toxicol. 47: 91-96.

Keller, A. E. Unpublished. Personal communication to U.S. EPA.

Keller, A.E. and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environ. Toxicol. Chem. 10: 539-546.

Kelly, M.G. and B.A. Whitton. 1989. Interspecific differences in Zn, Cd and Pb accumulation by freshwater algae and bryophytes. Hydrobiol. 17: 1-11.

Kerfoot, W.B. and S.A. Jacobs. 1976. Cadmium accrual in combined waste-treatment aquaculture system. Environ. Sci. Technol. 10: 662.

Kessler, E. 1985. An extremely cadmium-sensitive strain of *Chlorella*. Experientia. 41: 1621.

Kessler, E. 1986. Limits of growth of five *Chlorella* species in the presence of toxic heavy metals. Arch. Hydrobiol. 71(1): 123-128.

Kettle, W.D. and F. deNoyelles, Jr. 1986. Effects of cadmium stress on the plankton communities of experimental ponds. J. Freshwater Ecol. 3(4): 433-443.

Khan, A.T. and J.S. Weis. 1993. Bioaccumulation of heavy metals in two populations of mummichog (*Fundulus heteroclitus*). Bull. Environ. Contam. Toxicol. 51: 1-5.

Khan, A.T., J.S. Weis and L. D'Andrea. 1988. Studies of cadmium tolerance in two populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 40: 30-34.

Khan, A.T., J.S. Weis and L. D'Andrea. 1989. Bioaccumulation of four heavy metals in tow populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 42: 339-343.

Khan, A.T., J. Barbieri, S. Khan and F. Sweeney. 1992. A new short-term mysid toxicity test using sexual maturity as an endpoint. Aquat. Toxicol. 23: 97-105.

Khangarot, B.S. 1991. Toxicity of metals to a freshwater tubificid worm, *Tubifex tubifex* (Muller). Bull. Environ. Contam. Toxicol. 46: 906-912.

Khangarot, B.S. and P.K. Ray. 1987a. Correlation between heavy metal acute toxicity values in *Daphnia magna* and fish. Bull. Environ. Contam. Toxicol. 38: 722-726.

Khangarot, B.S. and P.K. Ray. 1987b. Sensitivity of toad tadpoles, *Bufo melanostictus* (Schneider), to heavy metals. Bull. Environ. Contam. Toxicol. 38(3): 523-527.

Khangarot, B.S. and P.K. Ray. 1989a. Investigation of correlation between physicochemical properties of metals and their toxicity to the water flea *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 18: 109-120.

Khangarot, B.S. and P.K. Ray. 1989b. Sensitivity of midge larvae of *Chironomus tentans* Fabricius (Diptera: Chironomidea) to heavy metals. Bull. Environ. Contam. Toxicol. 1989. 42: 325-330.

Khangarot, B.S., P.K. Ray and H. Chandra. 1987. *Daphnia magna* as a model to assess heavy metal toxicity: comparative assessment with mouse system. Acta Hydrochim. Hydrobiol. 15(4): 427-432.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1996. Cadmium uptake by unicellular green microalgae. Chem. Eng. J. 62: 81-88.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1997. Cell surface area as a major parameter in the uptake of cadmium by unicellular green microalgae. Chem. Eng. J. 65: 13-19.

Khristoforova, N.K., S.M. Gnezdilova and G.A. Vlasova. 1984. Effect of cadmium on gametogenesis and offspring of the sea urchin *Strongylocentrotus intermedius*. Mar. Ecol. Prog. Ser. 17: 9-14.

Kiffney, P.M. and W.H. Clements. 1996. Size-dependent response of macroinvertebrates to metals in experimental streams. Environ. Toxicol. Chem. 15(8): 1352-1356.

Klass, E., et al. 1974. The effect of cadmium on population growth of the green alga *Scenedesmus quadricauda*. Bull. Environ. Contam. Toxicol. 12: 442.

Klaverkamp, J.F. and D.A. Duncan. 1987. Acclimation to cadmium toxicity by white suckers: cadmium binding capacity and metal distribution in gill and liver cytosol. Environ. Toxicol. Chem. 6: 275-289.

Klerks, P.J. and P.R. Bartholomew. 1991. Cadmium accumulation and detoxification in a Cd-resistant population of the oligochaete *Limnodrilus hoffmeisteri*. Aquat. Toxicol. 19: 97-112.

Klockner, K. 1979. Uptake and accumulation of cadmium by *Ophryotrocha diadema* (Polychaeta). Mar. Ecol. Prog. Ser. 1: 71.

Kluttgen, B. and H.T. Ratte. 1994. Effects of different food doses on cadmium toxicity to *Daphnia magna*. Environ. Toxicol. Chem. 13(10): 1619-1627.

Kluytmand, J.H., D.I. Zandee and E.L. Enserink. 1988. Effects of cadmium on the reproduction of *Mytilus edulis* L. Aquat. Toxicol. 11:428-428

Kneip, T.J. and R.E. Hazen. 1979. Deposit and mobility of cadmium in marsh-cove ecosystem and the relation to cadmium concentration in biota. Environ. Health Perspect. 28: 67.

Kobayashi, N. 1971. Fertilized sea urchin eggs as an indicator material for marine pollution bioassay, preliminary experiments. Publ. Seto Mar. Biol. Lab. 18: 379.

Kock, G., R. Hofer and S. Wograth. 1995. Accumulation of trace metals (Cd, Pb, Cu, Zn) in arctic char (*Salvelinus alpinus*) from oligotrophic alpine lakes: relation to alkalinity. Can. J. Fish. Aquat. Sci. 52: 2367-2376.

Koelmans, A.A., F. Gillissen and L. Lijklema. 1996. Influence of salinity and mineralization on trace metal sorption to cyanobacteria in natural waters. Water Res. 30(4): 853-864.

Kohler, K. and H.U. Riisgard. 1982. Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*. Mar. Biol. 66: 53.

Koivisto, S., M. Arner and N. Kautsky. 1997. Does cadmium pollution change trophic interactions in rockpool food webs? Environ. Toxicol. Chem. 16(6): 1330-1336.

Kolok, A.S., E.P. Plaisance and A. Abdelghani. 1998. Individual variation in the swimming performance of fishes: an overlooked source of variation in toxicity studies. Environ. Toxicol. Chem. 17(2): 282-285.

Kooijman, S.A.L.M. and J.J.M. Bedaux. 1996. Analysis of toxicity tests on *Daphnia* survival and reproduction. Water Res. 30(7): 1711-1723.

Kosakowska, A., L. Falkowski and J. Lewandowska. 1988. Effect of amino acids on the toxicity of heavy metals to phytoplankton. Bull. Environ. Contam. Toxicol. 40: 532-538.

Koyama, J., R. Kuroshima and A. Ishimatsu. 1992. The seawater fish for evaluation of the toxicity of pollutants. Mizu Kankyo Gakkaishi. 15(11): 804-813.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1992a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. pp.139-143.

Kraak, M.H.S., D. Lavy, W.H.M. Peeters and C. Davids. 1992b. Chronic ecotoxicity of copper and cadmium to the zebra mussel *Dreissena polymorpha*. Arch. Environ. Contam. Toxicol. 23: 363-369.

Kraak, M.H.S., H. Schoon, W.H.M. Peeters and N.M. Van Straalen. 1993a. Chronic ecotoxicity of mixtures of Cu, Zn, and Cd to the zebra mussel *Dreissena polymorpha*. Ecotoxicol. Environ. Safety. 25: 315-327.

Kraak, M.H.S., D. Lavy, M. Toussaint, H. Schoon, W.H.M. Peeters and C. Davids. 1993b. Toxicity of heavy metals to the zebra mussel (*Dreissena polymorpha*). *In*: T.F. Nalepa and D.W. Schloessen (eds.), zebra mussels - biology, impacts, and control, chapter 29, Lewis Publishers, Boca Raton. 8: 491-502.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1994a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. 84(2): 139-143.

Kraak, M.H.S., D. Lavy, H. Schoon, M. Toussaint, W.H.M. Peeters and N.M. Van Straalen. 1994b. Ecotoxicity of mixtures of metals to the zebra mussel *Dreissena polymorpha*. Environ. Toxicol. Chem. 13: 109-114.

Kraak, M.H.S., Y.A. Wink, S.C. Stuijfzand, M.C. Buckert-de Jong, C.J. de Groot and W. Admiraal. 1994c. Chronic ecotoxicity of Zn and Pb to the zebra mussel *Dreissena polymorpha*. Aquat. Toxicol. 30: 77-89.

Kraal, M.H., M.H.S. Kraak, C.J. De Groot and C. Davids. 1995. Uptake and tissue distribution of dietary and aqueous cadmium by carp (*Cyprinus carpio*). Ecotoxicol. Environ. Safety. 31: 179-183.

Kramer, J.R., H.E. Allen, W. Davison, K.L. Godtfredsen, J.S. Meyer, E.M. Perdue, F. Tipping, D. Van de Meent and J.C. Westall. 1997. Chemical speciation and metal toxicity in surface waters. Pg 57-70. *In:* Reassessment of Metals Criteria for Aquatic Life Protection. H.L. Bergman and E.J. Dorward-King (Eds). SETAC Press, Pensacola, FL.

Krantzberg, G. 1989a. Accumulation of essential and nonessential metals by chironomid larvae in relation to physical and chemical properties of the elements. Can. J. Fish. Aquat. Sci. 46: 1755-1761.

Krantzberg, G. 1989b. Metal accumulation by chironomid larvae: the effects of age and body weight on metal body burdens. Hydrobiol. 188/189: 497-506.

Krantzberg, G. and P.M. Stokes. 1988. The importance of surface adsorption and pH in metal accumulation by chironomids. Environ. Toxicol. Chem. 7: 653-670.

Krantzberg, G. and P.M. Stokes. 1989. Metal regulation, tolerance, and body burdens in the larvae of the genus *Chironomus*. Can. J. Fish. Aquat. Sci. 46: 389-398.

Krassoi, F.R. and M. Julli. 1994. Chemical batch as a factor affecting the acute toxicity of the reference toxicant potassium dichromate to the cladoceran *Moina australiensis* (Sars). Bull. Environ. Contam. Toxicol. 53: 153-157.

Krawczynska, W., N.N. Pivovarova and A. Sobota. 1989. Effects of cadmium on growth, ultrastructure and content of chemical elements in *Tetrahymena pyriformis* and *Acanthamoeba castellanii*. Acta Protozool. 28:(3-4): 245-252.

Krishnaja, A.P., M.S. Rege and A.G. Joshi. 1987. Toxic effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab *Scylla serrata*. Environ. Res. 21: 109-119.

Kuhn, R. and M. Pattard. 1990. Results of the harmful effects of water pollutants to green algae (*Scenedesmus subspicatus*) in the cell multiplication inhibition test. Water Res. 24(1): 31-38.

Kuhn, R., M. Pattard, K.D. Pernak and A. Winter. 1989. Results of the harmful effects of water pollutants to *Daphnia magna* in the 21 day reproduction test. Water Res. 23(4): 501-510.

Kumada, H., et al. 1973. Acute and chronic toxicity, uptake and retention of cadmium in freshwater organisms. Bull. Freshwater Fish. Res. Lab. 22: 157.

Kumada, H., et al. 1980. Accumulation and biological effects of cadmium in rainbow trout. Bull. Jap. Soc. Sci. Fish. 46: 97.

Kumar, M. 1991. Accumulation of Pb, Cd, and Zn in aquatic snails from four freshwater sites in Steuben County, Indiana. Bios. 62(1): 2-8.

Kuroshima, R. 1987. Cadmium accumulation and it effect on calcium metabolism in the girella *Girella punctata* during a long term exposure. Bull. Jpn. Soc. Sci. Fish. 53(3): 445-450.

Kuroshima, R. 1992. Cadmium accumulation in the mummichog, *Fundulus heteroclitus*, adapted to various salinities. Bull. Environ. Contam. Toxicol. 49: 680-685.

Kuroshima, R. and S. Kimura. 1990. Changes in toxicity of Cd and its accumulation in girella and goby with their growth. Bull. Jpn. Soc. Sci. Fish. 56(3): 431-453.

Kuroshima, R., S. Kimura, K. Date and Y. Yamamoto. 1993. Kinetic analysis of cadmium toxicity to red sea bream, *Pagrus major*. Ecotoxicol. Environ. Safety. 25: 300-314.

Kwan, K.H.M. and S. Smith. 1991. Some aspects of the kinetics of cadmium and thallium uptake by fronds of *Lemna minor* L. New Phytologist. 117(1): 91-102.

Laegreid, M., et al. 1983. Seasonal variation of cadmium toxicity toward the alga *Selenastrum capricornutum* Printz in two lakes with different humus content. Environ. Sci. Technol. 17: 357.

Lagerwerff, J.V. and A.W. Specht. 1970. Contamination of roadside soil and vegetation with cadmium, nickel, lead and zinc. Environ. Sci. Technol. 4: 583-586.

Lalande, M. and B. Pinel-Alloul. 1986. Acute toxicity of cadmium, copper, mercury and zinc to *Tropocyclops Prasinus Mexicanus* (Cyclopoida, copepoda) from three Quebec lakes. Environ. Toxicol. Chem. 5:95-102.

Lam, P.K.S. 1996a. Effects of cadmium on the consumption and absorption rates of a tropical freshwater snail, *Radix plicatulus*. Chemosphere. 32(11): 2127-2132.

Lam, P.K.S. 1996b. Interpopulation differences in acute response of *Brotia hainanensis* (Gastropoda, Prosobranchia) to cadmium: genetic or environmental variance? Environ. Pollut. 94(1): 1-7.

Lam. P.K.S., K.N. Yu, K.P. Ng and M.W.K. Chong. 1997. Cadmium uptake and depuration in the soft tissues of *Brotia hainanensis* (Gastropoda: Prosobranchia: Thiaridae): a dynamic model. Chemosphere. 35(11): 2449-2461.

Landner, L. and A. Jernelov. 1969. Cadmium in aquatic systems. Metals and Ecology Symposium. Bulletin No. 5. Ecology Research Committee, Stockholm, Sweden. 47pp.

Lane, T.D. and F.M.M. Morel. 2000. A biological function for cadmium in marine diatoms. Proc. Natl. Acad. Sci. 97: 4627-4631.

Langston, W.J..and M. Zhou. 1987. Cadmium accumulation, distribution and metabolism in the gastropod *Littorina littorea*: the role of metal-binding proteins. J. Mar. Biol. Assoc. 67: 585-601.

Larsen, J. and B. Svensmark. 1991. Labile species of Pb, Zn and Cd determined by anodic stripping staircase voltammetry and their toxicity to *Tetrahymena*. Talanta. 38(9): 981-988.

Lasenby, D.C. and J. Van Duyn. 1992. Zinc and cadmium accumulation by the opossum shrimp *Mysis relicta*. Arch. Environ. Contam. Toxicol. 23: 179-183.

Lasheen, M.R., S.A. Shehata and G.H. Ali. 1990. Effect of cadmium, copper and chromium (VI) on the growth of nile water algae. Water, Air, Soil Pollut. 50: 19-30.

Laube, V.M., et al. 1980. Strategies of response to copper, cadmium, and lead by a blue-green and a green alga. Can. J. Microbiol. 26: 1300.

Lawrence, S.G. and M.H. Holoka. 1987. Effects of low concentrations of cadmium on the crustacean zooplankton community of an artificially acidified lake. Can. J. Fish. Aquat. Sci. 44: 163-172.

Lawrence, S.G. and M.H. Holoka. 1991. Response of crustacean zooplankton impounded *in situ* to cadmium at low environmental concentrations. Verh. Internat. Verein. Limnol. 24: 2254-2259.

LeBlanc, G.A. 1984. Interspecies relationships in acute toxicity of chemicals to aquatic organisms. Environ. Toxicol. Chem. 3: 47-60.

Lee, B.G. and S.N. Luoma. 1998. Influence of microalgal biomass on absorption efficiency of Cd, Cr, and Zn by two bivalves from San Francisco Bay. Limnol. Oceanogr. 43(7): 1455-1466.

Lee, H.H. and C.H. Xu. 1984. Differential response of marine organisms to certain metal and agrichemical pollutants. Bull. Environ. Contam. Toxicol. 33: 460-467.

Lee, H.L., B. Lustigman, V. Schwinge, I.Y. Chiu and S. Hsu. 1992. Effects of mercury and cadmium on the growth of *Anacystis nidulans*. Bull. Environ. Contam. Toxicol. 49: 272-278.

Lee, J.G., S.B. Roberts and F.M.M. Morel. 1995. Cadmium: a nutrient for the marine diatom *Thalassiosira weissflogii*. Limnol. Oceanogr. 40: 1056-1063.

Lee, R. and Y. Oshima. 1998. Effects of selected pesticides, metals and organometallics on development of blue crab (*Callinectes sapidus*) embryos. Mar. Environ. Res. 46(1-5): 479-482.

Lee, R.F., K. O'Malley and Y. Oshima. 1996. Effects of toxicants on developing oocytes and embryos of the blue crab, *Callinectes sapidus*. Mar. Environ. Res. 42(1-4): 125-128.

Lee, S. III, E.J. Na, Y.O. Cho, B. Koopman and G. Bitton. 1997. Short-term toxicity test based on algal uptake by *Ceriodaphnia dubia*. Water Environ. Res. 69(7): 1207-1210.

Leonhard, S.L., et al. 1980. Evaluation of the acute toxicity of the heavy metal cadmium to nymphs of the burrowing mayfly, *Hexagenia rigida*. *In:* J.F. Flannagan and K.E. Marshall (eds.), Advances in Ephemeroptera Biology. Plenum Publishing Corp., New York. p. 457.

Les, A. and R.W. Walter. 1984. Toxicity and binding of copper, zinc and cadmium by the blue-green alga, *Chroococcus paris*. Water, Air, Soil Pollut. 23: 129-130.

Lewis, P.A. and W.B. Horning II. 1991. Differences in acute toxicity test results of three reference toxicants on *Daphnia* at two temperatures. Environ. Toxicol. Chem. 10: 1351-1357.

Lewis, P.A. and C.I. Weber. 1985. A study of the reliability of *Daphnia* acute toxicity tests. *In:* Aquatic Toxicology and Hazard Assessment: Seventh Symposium. ASTM STP 854, R.D. Cardwell, R. Purdy and R.C. Bahner (eds.), American Society for Testing and Materials, Philadelphia. pp. 73-86.

Liao, I.C. and C.S. Hsieh. 1990. Toxicity of three heavy metals to *Macrobrachium rosenbergii*. *In*: Proc. of the 2nd Asian Fisheries Forum, April 17 - 22, 1989, Tokyo, Japan, Asian Fish. Soc., Manila, Philippines: 923-926.

Lin, H.C. and W.A. Dunson. 1993. The effect of salinity on the acute toxicity of cadmium to the tropical, estuarine, hermaphroditic fish, *Rivulus marmoratus*: a comparison of Cd, Cu, and Zn tolerance with *Fundulus heteroclitus*. Arch. Environ. Contam. Toxicol. 25: 41-47.

Lithner, G., K. Holm and H. Borg. 1995. Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden). Water, Air, Soil Pollut. 85: 785-790.

Lomagin, A.G. and L.V. Ul'yanova. 1993. A new bioassay on water pollution using duckweed *Lemna minor* L. Sov. Plant Physiol./Fiziol. Rast. 49(2): 283-284.

Lorz, H.W., et al. 1978. Effects of several metals on smolting of coho salmon. EPA-600/3-78-090. National Technical Information Service, Springfield, Virginia.

Loumbourdis, N.S., P. Kyriakopoulou-Sklavounou and G. Zachariadis. 1999. Effects of cadmium exposure on bioaccumulation and larval growth in the frog *Rana ridibunda*. Environ. Pollut. 104: 429-433.

Lourdes, M. 1994. Survival and heavy metal accumulation of two *Oreochromis niloticus* (L.) Strains exposed to mixtures of zinc, cadmium and mercury. Sci. Total Environ. 148: 31-38.

Lourdes, M. and E.V. Aralar. 1993. Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercury on two strains of tilapia *Oreochromis niloticus* (L.). Bull. Environ. Contam. Toxicol. 50: 891-897.

Lucker, T., D. Busch and W. Wosniok. 1997. Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771). Limnologica. 27: 91-101.

Lue-Kim, H., et al. 1980. Cadmium toxicity on synchronous populations of *Chlorella ellipsoidea*. Can. J. Biol. 58: 1780.

Lussier, S.M., et al. 1985. Acute and chronic effects of heavy metals and cyanide on *Mysidopsis bahia* (Crustacea: Mysidacea). Aquat. Toxicol. 7:25-35.

Lussier, S.M., W.S. Boothman, S. Poucher, D. Champlin and A. Helmstetter. 1995. Derivation of conversion factors for dissolved saltwater aquatic life criteria for metals - Draft Report to the Office of Water. U.S. EPA. ERL - Naragansett, RI. 55 pp.

Lussier, S.M., W.S. Boothman, S. Poucher, D. Champlin and A. Helmstetten. 1999. Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms. Environ. Toxicol. Chem. 18(5): 889-898

McCahon, C.P. and D. Pascoe. 1988a. Cadmium toxicity to the freshwater amphipod *Gammarus pulex* (L.) during the molt cycle. Freshwater Biol. 19: 197-203.

McCahon, C.P. and D. Pascoe. 1988b. Increased sensitivity to cadmium of the freshwater amphipod *Gammarus pulex* (L.) during the reproductive period. Aquat. Toxicol. 13: 183-194.

McCahon, C.P. and D. Pascoe. 1988c. Use of *Gammarus pulex* (L.) in safety evaluation tests: culture and selection of a sensitive life stage. Ecotoxicol. Environ. Safety. 15: 245-252.

McCahon, C.P. and D. Pascoe. 1991. Brief-exposure of first and fourth instar *Chironomus riparius* larvae to equivalent assumed doses of cadmium: effects on adult emergence. Water, Air, Soil Pollut. 60: 395-403.

McCahon, C.P., A.F. Brown and D. Pascoe. 1988. The effect of the acanthocephalan *Pomphorhynchus laevis* (Muller 1776) on the acute toxicity of cadmium to its intermediate host, the amphipod *Gammarus pulex* (L.). Arch. Environ. Contam. Toxicol 17: 239-243.

McCahon, C.P., A.J. Whiles and D. Pascoe. 1989. The toxicity of cadmium to different larval instars of the trichopteran larvae *Agapetus fuscipes* Curtis and the importance of life cycle information to the design of toxicity tests. Hydrobiol. 185: 153-162.

McCarty, L.S. and A.H. Houston. 1976. Effects of exposure to sublethal levels of cadmium upon water-electrolyte status in the goldfish (*Carassius auratus*). J. Fish. Biol. 9: 11.

McCarty, L.S., et al. 1978. Toxicity of cadmium to goldfish, *Carassius auratus*, in hard and soft water. J. Fish. Res. Board Can. 35: 35.

McClurg, T.P. 1984. Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*. Water SA 10: 40.

McGee, B.L., D.A. Wright and D.J. Fisher. 1998. Biotic factors modifying acute toxicity of aqueous cadmium to estuarine amphipod *Leptocheirus plumulosus*. Arch. Environ. Contam. Toxicol. 34: 34-40.

McGeer, J.C., R.C. Playle, C.M. Wood and F. Galvez. 2000. A physiologically based biotic ligand model for predicting the acute toxicity of waterborne silver to rainbow trout in freshwaters. Environ. Sci. Technol. 34: 4199-4207.

McLeese, D.W. and S. Ray. 1984. Uptake and excretion of cadmium, CdEDTA, and zinc by *Macoma balthica*. Bull. Environ. Contam. Toxicol. 32: 85.

McLeese, D.W. and S. Ray. 1986. Toxicity of $CdCl_2$, CdEDTA, $CuCl_2$, and CuEDTA to marine invertebrates. Bull. Environ. Contam. Toxicol. 36: 749-755.

McLeese, D.W., et al. 1981. Lack of excretion of cadmium from lobsters. Chemosphere 10: 775.

McNicol, R.E. and E. Scherer. 1993. Influence of cadmium pre-exposure on the preference-avoidance responses of lake whitefish (*Coregonus clupeaformis*) to cadmium. Arch. Environ. Contam. Toxicol. 25: 36-40.

McNulty, E.W., F.J. Dwyer, M.R. Ellersieck, E.I. Greer, C.G. Ingersoll and C.F. Rabeni. 1999. Evaluation of ability of reference toxicity tests to identify stress in laboratory populations of the amphipod *Hyalella azteca*. Environ. Toxicol. Chem. 18(3): 544-548.

Ma, M., Z. Tong, Z. Wang and W. Zhu. 1999. Acute toxicity bioassay using the freshwater luminescent bacterium *Vibrio-qinghaiensis sp.* Nov.-Q67. Bull. Environ. Contam. Toxicol. 62: 247-253.

Maas, R.P. 1978. A field study of the relationship between heavy metal concentrations in stream water and selected benthic macroinvertebrate species. PB 297284. National Technical Information Service, Springfield, Virginia.

Macdonald, C.R. and J.B. Sprague. 1998. Cadmium in marine invertebrates and arctic cod in the Canadian arctic. Distibution and ecological implications. Mar. Ecol. Prog. Ser. 47: 17-30.

Macdonald, J.M., J.D. Shields and R.K. Zimmer-Faust. 1988. Acute toxicities of eleven metals to early life-history stages of the yellow crab *Cancer anthonyi*. Mar. Biol. 98: 201-207.

Macfie, S.M., Y. Tarmohamed and P.M. Welbourn. 1994. Effects of cadmium, cobalt, copper, and nickel on growth of the green alga *Chlamydomonas reinhardtii*: the influences of the cell wall and pH. Arch. Environ. Contam. Toxicol. 27: 454-458.

MacInnes, J.R., et al. 1977. Long-term cadmium stress in the cunner *Tautogolabrus adspersus*. Fish. Bull. 75: 199.

Mackie, G.L. 1989. Tolerances of five benthic invertebrates to hydrogen ions and metals (Cd, Pb, Al). Arch. Environ. Contam. Toxicol. 18: 215-223.

Madoni, P., D. Davoli and G. Gorbi. 1994. Acute toxicity of lead, chromium, and other heavy metals to ciliates from activated sludge plants. Bull. Environ. Contam. Toxicol. 53: 420-425.

Maeda, S., M. Mizoguchi, A. Ohki and J. Inanaga. 1990. A bioaccumulation of zinc and cadmium in freshwater alga, *Chlorella vulgaris*. Part II. Association mode of the metals and cell tissue. Chemosphere. 21(8): 965-973.

Majewski, H.S. and M.A. Giles. 1984. Cardio vascular-respiratory responses of rainbow trout (*Salmo gairdneri*) during chronic exposure to sublethal concentrations of cadmium. Water Res. 15: 1211.

Malea, P. 1994. Uptake of cadmium and the effect on viability of leaf cells in the seagrass *Halophila stipulacea* (Forsk.) Aschers. Bot. Mar. 37: 67-73.

Malley, D.F. and P.S.S. Chang. 1991. Early observations on the zooplankton community of a precambrian shield lake receiving experimental additions of cadmium. Verh.-Int. Ver. Theor. Angew. Limnol. 24: 2248-2253.

Malley, D.F., P.S.S. Chang and R.H. Hesslein. 1989. Whole lake addition of cadmium-109: radiotracer accumulation in the mussel population in the first season. Sci. Total Environ. 87/88: 397-417.

Maloney, J. 1996. Influence of organic enrichment on the partitioning and bioavailability of cadmium in a microcosm study. Mar. Ecol. Prog. Ser. 144: 147-161.

Mansour, G.M.M. 1993. Effects on fish of cadmium concentrations in water. Oceanologia. 34: 91.

Manz, W., M. Wagner and D.H. Schleifer. 1994. *In situ* characterization of the microbial consortia active in two wastewater treatment plants. Water Res. 28(8): 1715-1732.

Maranhao, P., J.C. Marques and V.M.C. Madeira. 1999. Zinc and cadmium concentrations in soft tissues of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) after exposure to zinc and cadmium. Environ. Toxicol. Chem. 18(8): 1769-1771.

Mark, U. and J. Solbe. 1998. Analysis of the ecetoc aquatic toxicity (EAT) database V: The relevance of *Daphnia magna* as a representative test species. Chemosphere. 36(1): 155-166.

Markham, J.W., et al. 1980. Effects of cadmium on *Laminaria saccharina* in culture. Mar. Ecol. Prog. Ser. 3: 31.

Markich, S.J. and R.A. Jeffree. 1994. Absorption of divalent trace metals as analogues of calcium by Australian freshwater bivalves: an explanation of how water hardness reduces metal toxicity. Aquat. Toxicol. 29: 257-290.

Marr, J.C.A., H.L. Bergman, J. Lipton and C. Hogstrand. 1995a. Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. Can J. Aquat. Sci. 52: 2016-2030.

Marr, J.C.A., H.L. Bergman, M. Parker, J. Lipton, D. Cacela, W. Erickson and G.R Phillips. 1995b. Relative sensitivity of brown and rainbow trout to pulsed exposures of an acutely lethal mixture of metals typical of the Clark Fork River, Montana. Can. J. Aquat. Sci. 52: 2005-2015.

Marshall, J.S. 1978a. Population dynamics of *Daphnia galeata mendotae* as modified by chronic cadmium stress. J. Fish. Res. Board Can. 35: 461.

Marshall, J.S. 1978b. Field verification of cadmium toxicity to laboratory *Daphnia* populations. Bull. Environ. Contam. Toxicol. 20: 387.

Marshall, J.S., et al. 1981. An *in situ* study of cadmium and mercury stress in the plankton community of lake 382, Experimental Lakes Area, northwestern Ontario. Can. J. Fish. Aquat. Sci. 38: 1209.

Marshall, J.S., et al. 1983. Bioaccumulation and effects of cadmium and zinc in a Lake Michigan plankton community. Can. J. Fish. Aquat. Sci. 40: 1469.

Martin, M., K. Osborn, P. Billig and N. Glickstein. 1981. Toxicities of ten metals to *Crassostrea gigas* and *Mytilus edulis* embryos and *Cancer magister* larvae. Mar. Pollut. Bull. 12: 305.

Martin, T.R. and D.M. Holdich. 1986. The acute lethal toxicity of heavy metals to peracarid crustaceans (with particular reference to fresh-water asellids and gammarids). Water Res. 20(9): 1137-1147.

Martinez, M., J. Del Ramo, A. Torreblanca, A. Pastor and J. Diaz-Mayans. 1996. Cadmium toxicity, accumulation and metallothionein induction in *Echinogammarus echinosetosus*. J. Environ. Sci. Health. A31(7): 1605-1617.

Masters, J.A., M.A. Lewis and D.H. Davidson. 1991. Validation of a four-day *Ceriodaphnia* toxicity test and statistical considerations in data analysis. Environ. Toxicol. Chem. 10: 47-55.

Mateo, P., F. Fernandez-Pinas and I. Bonilla. 1994. O_2-induced inactivation of nitrogenase as a mechanism for the toxic action of Cd^{2+} on *Nostoc* UAM 208. New Phytologist. 126(2): 267-272.

Mathew, P. and N.R. Menon. 1992. Toxic responses of bivalves to metal mixtures. Bull. Environ. Contam. Toxicol. 48: 185-193.

Meador, J.P. 1993. The effect of laboratory holding on the toxicity response of marine infaunal amphipods to cadmium and tributyltin. J. Exp. Mar. Biol. Ecol. 174: 227-242.

Melgar, M.J., M. Perez, M.A. Garcia, J. Alonso and B. Miguez. 1997. Accumulation profiles in rainbow trout (*Oncorhynchus mykiss*) after short-term exposure to cadmium. J. Environ. Sci. Health. A32(3): 621-631.

Mersch, J., E. Morhain and C. Mouvet. 1993. Laboratory accumulation and depuration of copper and cadmium in the freshwater mussel *Dreissena polymorpha* and the aquatic moss *Rhynchostegium riparioides*. Chemosphere. 27(8): 1475-1485.

Mersch, J., P. Wagner and J.C. Pihan. 1996. Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight. Environ. Toxicol. Chem. 15(6): 886-893.

Metayer, C., et al. 1982. Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (*Solea solea*) and flounder (*Platichthus flesus*): changes as a function of age and organotropism. Rev. Int. Oceanogr. Med. 66-67: 33.

Meteyer, M.J., D.A. Wright and F.D. Martin. 1988. Effect of cadmium on early developmental stages of the sheepshead minnow (*Cyprinodon variegatus*). Environ. Toxicol. Chem. 7:321-328.

Meyer, J.S. 1999. A mechanistic explanation for the ln(LC50) vs ln(hardness) adjustment equation for metals. Environ. Sci. Technol. 33: 908-912.

Meyer, J.S., R.C. Santore, J.P. Bobbitt, L.D. Debrey, C.J. Boese, P.R. Paquin, H.E. Allen, H.L. Bergman and D.M. DiToro. 1999. Binding of nickel and copper to fish gills predicts toxicity when water hardness varies, but free-ion activity does not. Environ. Sci. Technol. 33: 913-916.

Michibata, H., S. Sahara and M.K. Kojima. 1986. Effects of calcium and magnesium ions on the toxicity of cadmium to the egg of the teleost, *Oryzias latipes*. Environ. Res. 40: 110-114.

Michibata, H., Y. Nojima and M.K. Kojima. 1987. Stage sensitivity of eggs of the teleost *Oryzias latipes* to cadmium exposure. Environ. Res. 42: 321-327.

Middaugh, D.P. and J.M. Dean. 1977. Comparative sensitivity of eggs, larvae and adults of the estuarine teleosts, *Fundulus heteroclitus* and *Menidia menidia* to cadmium. Bull. Environ. Contam. Toxicol. 17: 645.

Middaugh, D.P. and G. Floyd. 1978. The effect of prehatch and posthatch exposure to cadmium on salinity tolerance of larval grass shrimp, *Palaemonetes pugio*. Estuaries 1: 123.

Middaugh, D.P., et al. 1975. The response of larval fish *Leiostomus xanthurus* to environmental stress following sublethal cadmium exposure. Contrib. Mar. Sci. 19.

Migliore, J. and M. De Nicola Giudici. 1988. Effect of heavy metals (Hg, Cd, Cu and Fe) on two species of crustacean isopods, *Asellus aquaticus* (L.) and *Proasellus coxalis* Dollf. Verh.-Int. Ver. Theor. Angew. Limnol. 23: 1655-1659.

Ministry of Technology. 1967. Water Pollut. Res. 1966. London. p. 50

Mirenda, R.J. 1986. Toxicity and accumulation of cadmium in the crayfish, *Orconectes virilis* (Hagen). Arch. Environ. Contam. Toxicol. 15: 401-407.

Mirkes, D.Z., et al. 1978. Effects of cadmium and mercury on the behavioral responses and development of *Eurypanopeus depressus* larvae. Mar. Biol. 47: 143.

Mizutani, A., E. Ifune, A. Zanella and C. Eriksen. 1991. Uptake of lead, cadmium and zinc by the fairy shrimp, *Branchinecta longiantenna* (Crustacea: Anostraca). Hydrobiol. 212: 145-149.

Moller, V., V.E. Forbes and M.H. Depledge. 1994. Influence of acclimation and exposure temperature on the acute toxicity of cadmium to the freshwater snail *Potamopyrgus antipodarum* (Hydrobiidae). Environ. Toxicol. Chem. 13(9): 1519-1524.

Moore, M.N. and A.R.D. Stebbing. 1976. The quantitative cytochemical effects of three metal ions on a lysosomal hydrolase of a hydroid. J. Mar. Biol. Assoc. U.K. 56: 995.

Moraitou-Apostolopoulou, M. and G. Verriopoulos. 1982. Individual and combined effects of three heavy metals, Cu, Cd and Cr for the marine copepod *Tisbe holothuriae*. Hydrobiol. 87: 83.

Moraitou-Apostolopoulou, M., G. Verriopoulos and P. Lentzou. 1979. Effects of sublethal concentrations of cadmium pollution for two populations of *Acartis clausi* (Copepoda) living at two differently polluted areas. Bull. Environ. Contam. Toxicol. 23: 642-649.

Morel, F.M.M. and J.G. Hering. 1993. Principals and Applications of Aquatic Chemistry. J. Wiley, New York. 588 pp.

Morgan, W.S.G. 1979. Fish locomotor behavior patterns as a monitoring tool. J. Water Pollut. Control Fed. 51: 580.

Mostafa, L.Y. and Z. Khalil. 1986. Uptake, release and incorporation of radio active cadmium and mercury by the fresh water alga *Phormidium fragile*. Isot. Rad. Res. 18(1): 57-62.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life-cycle cladoceran toxicity test. Environ. Toxicol. Chem. 3: 425.

Mount, D.R., A.K. Barth, T.D. Garrison, D.A. Barten and J.R. Hockett. 1994. Dietary and waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium, lead and zinc using a live diet. Environ. Toxicol. Chem. 13(12): 2031-2041.

Moza, U., S.S. De Solva and B.M. Mitchell. 1995. Effect of sub-lethal concentrations of cadmium on food intake, growth and digestibility in the gold fish, *Carassius auratus* L. J. Environ. Biol. 16(3): 253-264.

Muino, C.V., L. Ferrari and A. Salibian. 1990. Protective action of ions against cadmium toxicity to young *Bufo arenarum* tadpoles. Bull. Environ. Contam. Toxicol. 45: 313-319.

Muller, K.W. and H.D. Payer. 1979. The influence of pH on the cadmium-repressed growth of the alga *Coelostrum proboscideum*. Physiol. Plant. 45: 415.

Muller, K.W. and H.D. Payer. 1980. The influence of zinc and light conditions on the cadmium-repressed growth of the green alga *Coelostrum proboscideum*. Physiol. Plant. 50: 265.

Munger, C. and L. Hare. 1997. Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): implications for predicting Cd bioaccumulation in nature. Environ. Sci. Technol. 31: 891-895.

Munger, C., et al. 1999. Influence of exposure time on the distribution of cadmium within the cladoceran *Ceriodaphnia dubia*. Aquat. Toxicol. 44: 195-200.

Muramoto, S. 1980. Decrease in cadmium concentration in a Cd-contaminated fish by short-term exposure to EDTA. Bull. Environ. Contam. Toxicol. 25: 828.

Musko, I.B., W. Meinel, R. Krause and M. Barlas. 1990. The impact of Cd and different pH on the amphipod *Gammarus fossarum* Koch (Crustacea: amphipoda). Comp. Biochem. Physiol. 96C(1): 11-16.

Mwangi, S.M. and M.A. Alikhan. 1993. Cadmium and nickel uptake by tissues of *Cambarus bartoni* (Astacidae, Decapoda, Crustacea): effects on copper and zinc stores. Water Res. 27(5): 921-927.

Nacci, D., E. Jackim and R. Walsh. 1986. Comparative evaluation of three rapid marine toxicity tests: sea urchin early embryo growth test, sea urchin sperm cell toxicity test and Microtox. Environ. Toxicol. Chem. 5: 521-525.

Nagel, K. and J. Voigt. 1995. Impaired photosynthesis in a cadmium-tolerant *Chlamydomonas* mutant strain. Microbiol. Res. 150: 105-110.

Nakagawa, H. and S. Ishio. 1988. Aspects of accumulation of cadmium ion in the egg of medaka *Oryzias latipes*. Bull. Jpn. Soc. Sci. Fish. 54(12): 2159-2164.

Nakagawa, H. and S. Ishio. 1989. Effects of water hardness on the toxicity and accumulation of cadmium in eggs and larvae of medaka *Oryzias latipes*. Bull. Jpn. Soc. Sci. Fish. 55(2): 327-331.

Nakano, Y. 1980. Chloroplast replication in *Euglena gracilis* grown in cadmium ion containing media. Agric. Biol. Chem. 44: 2733.

Nakano, Y., et al. 1980. Morphological observation of *Euglena gracilis* grown in zinc-sufficient media containing cadmium ions. Agric. Biol. Chem. 44: 2305.

Nalecz-Jawecki, G. and J. Sawicki. 1998. Toxicity of inorganic compounds in the spirotox test: a miniaturized version of the *Spirostomum ambiguum* test. Arch. Environ. Contam. Toxicol. 34: 1-5.

Nalecz-Jawecki, G., K. Demkowicz-Dobrzanski and J. Sawicki. 1993. Protozoan *Spirostomum ambiguum* as a highly sensitive bioindicator for rapid and easy determination of water quality. Sci. Total Environ. Supplemental Part 2: 1227-1234.

Nalewajko, C. 1995. Effects of cadmium and metal-contaminated sediments on photosynthesis heterotrophy, and phosphate uptake in Mackenzie River delta phytoplankton. Chemosphere. 30(7): 1401-1414.

Naqvi, S.M. and R.D. Howell. 1993. Toxicity of cadmium and lead to juvenile red swamp crayfish, *Procambarus clarkii*, and effects on fecundity of adults. Bull. Environ. Contam. Toxicol. 51: 303-308.

Nassiri, Y., J. Wery, J.L. Mansot and T. Ginsburger-Vogel. 1997. Cadmium bioaccumulation in *Tetraselmis suecica*: and electron energy loss spectroscopy (EELS) study. Arch. Environ. Contam. Toxicol. 33: 156-161.

Nasu, Y., K. Hirabayashi and M. Kugimoto. 1988. The toxicity of some water pollutants for lemnaceae (duckweed) plant. Proc. ICMR Semin. 8: 485-491.

Nasu, Y., et al. 1983. Comparative studies on the absorption of cadmium and copper in *Lemna paucicostata*. Environ. Pollut. (Series A) 32: 201.

Naylor, C., E.J. Cox, M.C. Bradley and P. Calow. 1992. Effect of differing maternal food ration on susceptibility of *Daphnia magna* Straus neonates to toxic substances. Aquat. Toxicol. 24: 75-82.

Nebeker, A.V., M.A. Cairns, S.T. Onjukka and R.H. Titus. 1986a. Effect of age on sensitivity of *Daphnia magna* to cadmium, copper and cyanazine. Environ. Toxicol. Chem. 5: 527-530.

Nebeker, A.V., S.T. Onjukka, M.A. Cairns and D.F. Krawczyk. 1986b. Survival of *Daphnia magna* and *Hyalella azteca* in cadmium-spiked water and sediment. Environ. Toxicol. Chem. 5: 933-938.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1994. Effects of cadmium on limb regeneration in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 27: 318-322.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1995. Effects of cadmium on growth and bioaccumulation in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 29: 492-499.

Negilski, D.S. 1976. Acute toxicity of zinc, cadmium and chromium to the marine fishes, yellow-eye mullet (*Aldrichetta forsteri* C. and V.) and smallmouth hardy head (*Atherinasoma microstoma* Whitley). Aust. J. Mar. Freshwater Res. 27: 137.

Nelson, D.A., et al. 1976. Biological effects of heavy metals on juvenile bay scallops, *Argopecten irradians*, in short-term exposures. Bull. Environ. Contam. Toxicol. 16: 275.

Nelson, D.A., J.E. Miller and A. Calabrese. 1988. Effect of heavy metals on bay scallops, surf clams, and blue mussels in acute and long-term exposures. Arch. Environ. Contam. Toxicol. 17: 595-600.

Nelson, S.M. 1994. Observed field tolerance of caddisfly larvae (*Hesperophylax sp.*) to fish metal concentrations and low pH. J. Freshwater Ecol. 9(2): 169-170.

Nelson, S.M. and R.A. Roline. 1998. Evaluation of the sensitivity of rapid toxicity tests relative to daphnid acute lethality tests. Bull. Environ. Contam. Toxicol. 60: 292-299.

Nendza, M., T. Herbst, C. Kussatz and A. Gies. 1997. Potential for secondary poisoning and biomagnification in marine organisms. Chemosphere. 35(9): 1875-1885.

Neter, J. and W. Wasserman. 1974. Applied Linear Statistical Models. Irwin, Inc., Homewood, Illinois.

Niederlehner, B. 1984. A comparison of techniques for estimating the hazard of chemicals in the aquatic environment. M.S. thesis. Virginia Polytechnic Institute and State University.

Niederlehner, B.R., et al. 1985. Laboratory test evaluating the effects of cadmium on freshwater protozoan communities. Environ. Toxicol. Chem. 4: 155-165.

Nilsson, R. 1970. Aspects on the toxicity of cadmium and its compounds: a review. Ecol. Res. Comm. Bull. 7, Swed. Natur. Sci. Res. Council. Stockholm. 49 pp.

Nimmo, D.R., et al. 1977a. *Mysidopsis bahia*: an estuarine species suitable for life-cycle toxicity tests to determine the effects of a pollutant. *In:* F.L. Mayer and J.L. Hamelink (eds.), Aquatic Toxicology and Hazard Evaluation. ASTM STP 634. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 109.

Nimmo, D.R., et al. 1977b. Effects of cadmium on the shrimps *Penaeus duorarum*, *Palaemonetes pugio*, and *Palaemonetes vulgaris*. *In:* F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 131.

Nir, R., A. Gasith and A.S. Perry. 1990. Cadmium uptake and toxicity to water hyacinth: effect of repeated exposures under controlled conditions. Bull. Environ. Contam. Toxicol. 44: 149-157.

Noel-Lambot, F., et al. 1980. Cadmium, zinc, and copper accumulation in limpets (*Patella vulgata*) from the British channel and special reference to metallothioneins. Mar. Ecol. Prog. Ser. 2: 81.

Nolan, C.V. and E.J. Duke. 1983. Cadmium accumulation and toxicity in *Mytilus edulis*: involvement of metallothioneins and heavy molecular weight protein. Aquat. Toxicol. 4: 153.

Noraho, N. and J.P. Gaur. 1995. Effect of cations, including heavy metals, on cadmium uptake by *Lemna polyrhiza* L. BioMetals. 8: 95-98.

Norey, C.G., M.W. Brown, A. Cryer and J. Kay. 1990a. A comparison of the accumulation, tissue distribution and secretion of cadmium in different species of freshwater fish. Comp. Biochem. Physiol. 96C(1): 181-184.

Norey, C.G., A. Cryer and J. Kay. 1990b. Cadmium uptake and sequestration in the pike (*Esox lucius*) Comp. Biochem. Physiol. 95C(2): 217-221.

Notenboom, J., K. Cruys, J. Hoekstra and P. Van Beelen. 1992. Effect of ambient oxygen concentration upon the acute toxicity of chlorophenols and heavy metals to the groundwater copepod *Parastenocaris germanica* (crustacea). Ecotoxicol. Environ. Safe. 24: 131-143.

Nott, J.A. and A. Nicolaidou. 1994. Variable transfer of detoxified metals from snails to hermit crabs in marine food chains. Mar. Biol. 120: 369-377.

Nugegoda, D. and P.S. Rainbow. 1995. The uptake of dissolved zinc and cadmium by the decapod crustacean *Palaemon elegans*. Mar. Pollut. Bull. 31(4-12): 460-463.

O'Hara, J. 1973a. The influence of temperature and salinity on the toxicity of cadmium to the fiddler crab, *Uca pugilator*. Fish. Bull. 71: 149.

O'Hara, J. 1973b. Cadmium uptake by fiddler crabs exposed to temperature and salinity stress. J. Fish. Res. Board Can. 30: 846.

O'Neill, J.G. 1981. Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*. Bull. Environ. Contam. Toxicol. 27: 42.

Oakley, S.M., et al. 1983. Accumulation of cadmium by *Abarenicola pacifica*. Sci. Total Environ. 28: 105.

Odin, M., F. Ribeyre and A. Boudou. 1996. Temperature and pH effects on cadmium and methylmercury bioaccumulation by nymphs of the burrowing mayfly *Hexagenia rigida*, from water column or sediment source. Arch. Environ. Contam. Toxicol. 31: 339-349.

Odin, M., F. Ribeyre and A. Boudou. 1997. Depuration processes after exposure of burrowing mayfly nymphs (*Hexagenia rigida*) to methylmercury and cadmium from water column or sediment: effects of temperature and pH. Aquat. Toxicol. 37: 125-137.

Oikari, A., J. Kukkonen and V. Virtanen. 1992. Acute toxicity of chemicals to *Daphnia magna* in humic water. Sci. Total Environ. 117/118: 367-377.

Ojaveer, E., et al. 1980. On the effect of copper, cadmium and zinc on the embryonic development of Baltic spring spawning herring. Finnish Mar. Res. 247: 135.

Okamoto, O.K., C.S. Asano, E. Aidar and P. Colepicolo. 1996. Effects of cadmium on growth and superoxide dismutase activity of the marine microalga *Tetraselmis gracilis* (Prasinophyceae) J. Physiol. 32: 74-79.

Olesen, T.M.E. and J.M. Weeks. 1994. Accumulation of Cd by the marine sponge *Halichondria panicea* Pallas: effects upon filtration rate and its relevance for biomonitoring. Bull. Environ. Contam. Toxicol. 52: 722-728.

Onuoha, G.C., F.O. Nwadukwe and E.S. Erondu. 1996. Comparative toxicity of cadmium to crustacean zooplankton (copepods and ostracods) Environ. Ecol. 14(3); 557-562.

Oronsaye, J.A.O. 1989. Histological changes in the kidneys and gills of the stickleback, *Gasterosteus aculeatus* L, exposed to dissolved cadmium in hard water. Ecotox. Environ. Safety. 17: 279-290.

Outridge, P.M. 1992. Comparing Cd toxicity tests with plants in monocultures and species mixtures. Bull. Environ. Contam. Toxicol. 48: 344-351.

Pagenkopf, G.K. 1983. Gill surface interaction model for trace-metal toxicity to fishes: Role of complexation, pH and water hardness. Environ. Sci. Technol. 17: 342-347.

Palackova, J., D. Pravda, K. Fasaic and O. Celechovska. 1994. Sublethal effects of cadmium on carp (*Cyprinus carpio*) fingerlings. *In:* R. Muller and R. Lloyd (eds.), Sublethal and chronic effects of pollutants on freshwater fish, chapter 5, Fishing News Books, London: pp. 53-61.

Palawski, D., J.B. Hunn and F.J. Dwyer. 1985. Sensitivity of young striped bass to organic and inorganic contaminants in fresh and saline water. Trans. Am. Fish. Soc. 114: 748-753.

Pantani, C., G. Pannunzio, M. De Cristofaro, A.A. Novelli and M. Salvatori. 1997. Comparative acute toxicity of some pesticides, metals, and surfactants to *Gammarus italicus* Goedm. and *Echinogammarus tibaldii* Pink. and stock (Crustacea: Amphipoda). Bull. Environ. Contam. Toxicol. 59(6): 963-967.

Papathanassiou, E. 1983. Effects of cadmium and mercury ions on respiration and survival of the common prawn *Palaemon serratus* (Pennant). Rev. Int. Oceanogr. Med. 72: 21-35.

Papathanassiou, E. 1986. Cadmium accumulation and ultrastructural alterations in oogenesis of the prawn *Palaemon serratus* (Pennant). Bull. Environ. Contam. Toxicol. 36: 192-198.

Papoutsoglou, S.E. and P.D. Abel. 1988. Sublethal toxicity and accumulation of cadmium in *Tilapia aurea*. Bull. Environ. Contam. Toxicol. 41: 404-411.

Papoutsoglou, S.E. and D. Abel. 1993. Studies on the lethal and sublethal effects of cadmium on some commercially cultured species of the Mediterranean. *In*: Final Reports on Projects (activity G), UNEP Mediterranean Action Plan, Athens, Greece. MAP Tech. Rep. Ser. No. 48: pp. 33-43.

Paquin, P., D. DiToro, R.C. Santore, B. Trivedi and B. Wu. 1999. A biotic ligand model of the acute toicity of metals III: Application to fish and daphnia exposure to silver. U.S. Government Printing Office: Washington, D.C. EPA-E-99-001.

Pardue, W.J. and T.S. Wood. 1980. Baseline toxicity data for freshwater bryoza exposed to copper, cadmium, chromium, and zinc. J. Tennessee Acad. Sci. 55: 27.

Park, E.H., H.H. Chang, W.N. Joo, H.S. Chung and H.S. Kwak. 1994. Assessment of the estuarine hermaphroditic fish *Rivulus marmoratus* as a useful euryhaline species for acute toxicity tests as shown using cadmium. Can. J. Fish. Aquat. Sci. 51: 280-285.

Parker, J.G. 1984. The effects of selected chemicals and water quality on the marine polychaete *Ophryotrocha diadema*. Water Res. 18: 865.

Pascoe, D. and P. Cram. 1977. The effect of parasitism on the toxicity of cadmium to the three-spined stickleback, *Gasterosteus aculeatus* L. J. Fish. Biol. 10: 467.

Pascoe, D. and D.L. Mattey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback *Gasterosteus aculeatus* L. J. Fish. Biol. 11: 207.

Pascoe, D. and N.A.M. Shazili. 1986. Episodic pollution - a comparison of brief and continuous exposure of rainbow trout to cadmium. Ecotoxicol. Environ. Safety. 12: 189-198.

Pascoe, D., S.A. Evans and J. Woodworth. 1986. Heavy metal toxicity to fish and the influence of water hardness. Arch. Environ. Contam. Toxicol. 15: 481-487.

Pascoe, D., K.A. Williams and D.W.J. Green. 1989. Chronic toxicity of cadmium to *Chironomus riparius* Meigen - effects upon larval development and adult emergence. Hydrobiol. 175: 109-115.

Pascoe, D., A.F. Brown, B.M.J. Evans and C. McKavanagh. 1990. Effects and fate of cadmium during toxicity tests with *Chironomus riparius* - the influence of food and artificial sediment. Arch. Environ. Contam. Toxicol. 19: 872-877.

Pauli, W. and S. Berger. 1997. Toxicological comparisons of *Tetrahymena* species, end points and growth media: supplementary investigations to the pilot ring test. Chemosphere. 35(5): 1043-1052.

Pavicic, J., M. Skreblin, I. Kregar, M. Tusek-Znidaric and P. Stegnar. 1994. Embryo-larval tolerance of *Mytilus galloprovincialis*, exposed to the elevated sea water metal concentrations - I. Toxic effects of Cd, Zn and Hg in relation to the metallothionein level. Comp. Biochem. Physiol. 107C(2): 249-257.

Pawlik, B. and T. Skowronski. 1994. Transport and toxicity of cadmium: its regulation in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 34(2): 225-233.

Pawlik, B., T. Skowronski, Z. Ramazanow, P. Gardestrom and G. Samuelsson. 1993. pH-dependent cadmium transport inhibits photosynthesis in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 33(2): 331-337.

Pecon, J. and E.N. Powell. 1981. Effect of the amino acid histidine on the uptake of cadmium from the digestive system of the blue crab, *Callinectes sapidus*. Bull. Environ. Contam. Toxicol. 27: 34.

Pedersen, F. and G.I. Petersen. 1996. Variability of species sensitivity to complex mixtures. Water Sci. Tech. 33(6): 109-119.

Pelgrom, S.M.G.J., L.P.M. Lamers, J.A.M. Garritsen, B.M. Pels, R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1994. Interactions between copper and cadmium during single and combined exposure in juvenile tilapia *Oreochromis mossambicus*: influence of feeding condition on whole body metal accumulation and the effect of the metals on tissue water and ion content. Aquat. Toxicol. 30: 117-135.

Pelgrom, S.M.G.J., R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1997. Calcium fluxes in juvenile tilapia, *Oreochromis mossambicus*, exposed to sublethal waterborne Cd, Cu or mixtures of these metals. Environ. Toxicol Chem. 16(4): 770-774.

Pellegrini, M., A. Laugier, M. Sergent, R. Phan-Tan-Luu, R. Valls and L. Pellegrini. 1993. Interactions between the toxicity of the heavy metals cadmium, copper, zinc in combinations and the detoxifying role of calcium in the brown alga *Cystoseira barbata*. J. Appl. Phycol. 5: 351-361.

Pennington, C.H., et al. 1982. Contaminant levels in fishes from Brown's Lake, Mississippi. J. Mississippi Acad. Sci. 27: 139.

Penttinen, S., J. Kukkonen and A. Oikari. 1995. The kinetics of cadmium in *Daphnia magna* as affected by humic substances and water hardness. Ecotoxicol. Environ. Safety. 30: 72-76.

Penttinen, S., A. Kostamo and J.V.K. Kukkonen. 1998. Combined effects of dissolved organic material and water hardness on toxicity of cadmium to *Daphnia magna*. Environ. Toxicol. Chem. 17(12): 2498-2503.

Pereira, J.J., R. Mercaldo-Allen, C. Kuropat, D. Luedke and G. Sennefelder. 1993. Effect of cadmium accumulation on serum vitellogenin levels and hepatosomatic and gonadosomatic indices of winter flounder (*Pleuronectes americanus*). Arch. Environ. Contam. Toxicol. 24: 427-431.

Perez-Coll, C.S. and J. Herkovits. 1996. Stage-dependent uptake of cadmium by *Bufo arenarum* embryos. Bull. Environ. Contam. Toxicol. 56: 663-669.

Pesch, G.G. and N.E. Stewart. 1980. Cadmium toxicity to three species of estuarine invertebrates. Mar. Environ. Res. 3: 145.

Pesonen, M. and T.B. Andersson. 1997. Fish primary hepatocyte culture; and important model for xenobiotic metabolism and toxicity studies. Aquat. Toxicol. 37: 253-267.

Peterson, H.G. 1991. Toxicity testing using a chemostat-grown green alga, *Selenastrum capricornutum*. *In:* J.W. Garoch, W.K. Lower, W. Wang and M.A. Lewis (eds.), Plants for toxic assessment, 2nd Volume, ASTM STP 1115, Philadelphia, PA: pp. 107-117.

Peterson, H.G., F.P. Healey and R. Wagemann. 1984. Metal toxicity to algae: a highly pH dependent phenomenon. Can. J. Fish. Aquat. Sci. 41: 974-979.

Peterson, R.H., et al. 1983. Effects of cadmium on yolk utilization, growth, and survival of Atlantic salmon alevins on newly feeding fry. Arch. Environ. Contam. Toxicol. 12: 37.

Peterson, R.H., J.L. Metcalfe and S. Ray. 1985. Uptake of cadmium by eggs and alevins of Atlantic salmon (*Salmo salar*) as influenced by acidic conditions. Bull. Environ. Contam. Toxicol. 34: 359-368.

Phelps, H.L. 1979. Cadmium sorption in estuarine mud-type sediment and the accumulation of cadmium in the soft-shell clam, *Mya arenaria*. Estuaries 2: 40.

Phillips, D.J.H. 1976. The common mussel *Mytilus edulis* as an indicator of pollution by zinc, cadmium, lead and copper. I. Effects of environmental variables on uptake of metals. Mar. Biol. 38: 59.

Phillips, G.R. and R.C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: a literature review. EPA-600/3-78-103. National Technical Information Service, Springfield, Virginia.

Phipps, G.L. and G.W. Holcombe. 1985. A method for aquatic multiple species toxicant testing: acute toxicity of 10 chemicals to 5 vertebrates and 2 invertebrates. Environ. Pollut. (Series A). 38: 141-157.

Phipps, G.L., V.R. Mattson and G.T. Ankley. 1995. Relative sensitivity of three freshwater benthic macroinvertebrates to ten contaminants. Arch. Environ. Contam. Toxicol. 28: 281-286.

Pickering, Q.H. and M.H. Gast. 1972. Acute and chronic toxicity of cadmium to the fathead minnow (*Pimephales promelas*) J. Fish. Res. Board Can. 29: 1099.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. J. 10: 453.

Playle, R.C., D.G. Dixon and K. Burnison. 1993a. Copper and cadmium binding to fish gills: estimates of metal-gill stability constants and modelling of metal accumulation. Can. J. Fish. Aquat. Sci. 50: 2678-2687.

Playle, R.C., D.G. Dixon and K. Burnison. 1993b. Copper and cadmium binding to fish gills: modification by dissolved organic carbon and synthetic ligands. Can. J. Fish. Aquat. Sci. 50: 2667-2677.

Polar, E. and R. Kucukcezzar. 1986. Influence of some metal chelators and light regimes on bioaccumulation and toxicity of Cd^{2+} in duckweed (*Lemna gibba*). Physiol. Plant 66: 87-93.

Poldoski, J.E. 1979. Cadmium bioaccumulation assays. Their relationship to various ionic equilibria in Lake Superior water. Environ. Sci. Technol. 13: 701.

Postma, J.F. and C. Davids. 1995. Tolerance induction and life cycle changes in cadmium-exposed *Chironomus riparius* (Diptera) during consecutive generation. Ecotoxicol. Environ. Safety. 30: 195-202.

Postma, J.F., M.C. Buckert-de Jong, N. Staats and C. Davids. 1994. Chronic toxicity of cadmium to *Chironomus reparius* (Diptera: Chironomidae) at different food levels. Arch. Environ. Contam. Toxicol. 26: 143-148.

Postma. J.F., P. Van Nugteren and M.B. Buckert-De Jong. 1996. Increased cadmium excretion in metal-adapted populations of the midge *Chironomus riparius* (Diptera). Environ. Toxicol Chem. 15(3): 332-339.

Poulsen, E., et al. 1982. Accumulation of cadmium and bioenergetics in the mussel *Mytilus edulis*. Mar. Biol. 68: 25.

Poulton. B.C., D.P. Monda, D.F. Woodward, M.L.Wildhaber and W.G. Brumbaugh. 1995. Relations between benthic community structure and metals concentrations in aquatic macroinvertebrates: Clark Fork River, Montana. J. Freshwater Ecol. 10(3): 277-293.

Prasad, M.N.V., K. Drej, A. Skawinska and K. Stralka. 1998. Toxicity of cadmium and copper in *Chlamydomonas reinhardtii* wild-type (WT2137) and cell wall deficient mutant strain (CW15). Bull. Environ. Contam. Toxicol. 60: 306-311.

Presing, M., K.V. Balogh and J. Salanki. 1993. Cadmium uptake and depuration in different organs of *Lymnaea stagnalis* L. and the effect of cadmium on the natural zinc level. Arch. Environ. Contam. Toxicol. 24: 28-34.

Prevot, P. and M.O. Soyer-Gobillard. 1986. Combined action of cadmium and selenium on two marine dinoflagellates in culture, *Prorocentrum micans* Ehrbg. and *Crypthecodinium cohnii* Biecheler. J. Protozool. 33(1): 42-47.

Price, N.M. and F.M.M. Morel. 1990. Cadmium and cobalt substitution for zinc in a zinc-deficient marine diatom. Nature 344: 658-660.

Pringle, B.H., et al. 1968. Trace metal accumulation by estuarine mollusks. Am. Soc. Civil Eng., J. Sanit. Eng. Div. 94: 455.

Prothro, M.G. 1993. Office of water policy and technical guidance on interpretation and implementation of aquatic metals criteria. Memorandum from Acting Assistant Administrator for Water. Washington, D.C., U.S. EPA Office of Water. 7 pp. Attachments 41pp.

Pynnonen, K. 1995. Effect of pH, hardness and maternal pre-exposure on the toxicity of Cd, Cu and Zn to the glochidial larvae of a freshwater clam *Anodonta cygnea*. Water Res. 29(1): 247-254.

Qichen, C., Z. Kejien and Z. Guanwen. 1988. A comprehensive investigation of the toxic effects of heavy metals on fish. J. Fish. China/Shuichan Xuebao (Chi.) (Eng. Trans.) (Author communication used). 12(1): 21-33.

Qureshi, S.A., et al. 1980. Acute toxicity of four heavy metals to benthic fish food organisms from the river Khan, Ujjain. Int. J. Environ. Studies 15: 59.

Rachlin, J.W. and A. Grosso. 1991. The effects of pH on the growth of *Chlorella vulgaris* and its interactions with cadmium toxicity. Arch. Environ. Contam. Toxicol. 20: 505-508.

Rachlin, J.W. and A. Grosso. 1993. The growth response of the green alga *Chlorella vulgaris* to combined divalent cation exposure. Arch. Environ. Contam. Toxicol. 24:16-20.

Rachlin, J.W., et al. 1982. The growth responses of *Chlorella saccharophila*, *Navicula incerta* and *Nitzschia closterium* to selected concentrations of cadmium. Bull. Torrey Bot. Club 109: 129.

Rachlin, J.W., et al. 1984. The toxicological response of the algae *Anabaena flos-aquae* (Cyanophyceae) to cadmium. Arch. Environ. Contam. Toxicol. 13: 143.

Radetski, C.M., J.F. Ferard and C. Blaise. 1995. A semistatic microplate-based phytotoxicity test. Environ. Toxicol. Chem. 14(2): 299-302.

Radix, P., M. Leonard, C. Papantoniou, G. Roman, E. Saouter, S. Gallotti-Schmitt, H. Threbaud and P. Vasseur. 1999. Comparison of *Brachionus calyciflorus* 2-D and microtox® chronic 22-h tests with *Daphnia magna* 21-D test for chronic toxicity assessment of chemicals. Environ. Toxicol. Chem. 18(10): 2178-2185.

Rai, U.N., R.D. Tripathi, S. Sinha and P. Chandra. 1995. Chromium and cadmium bioaccumulation and toxicity in *Hydrilla verticillata* (l.f.) Royle and *Chara corallina* Wildenow. J. Environ. Sci. Health. A30: 537-551.

Rainbow, P.S. 1985. Accumulation of Zn, Cu and Cd by crabs and barnacles. Estuarine Coastal Shelf Sci. 21: 669-686.

Rainbow, P.S. and M.K.H Kwan. 1995. Physiological responses and the uptake of cadmium and zinc by the amphipod crustacean *Orchestia gammarellus*. Mar. Ecol. Prog. Ser. 127: 87-102.

Rainbow, P.S. and S.L. White. 1989. Comparative strategies of heavy metal accumulation by crustaceans: zinc, copper and cadmium in a decapod, and amphipod and a barnacle. Hydrobiol. 174: 245-262.

Rainbow, P.S., et al. 1980. Effects of chelating agents on the accumulation of cadmium by the barnacle *Semibalanus balanoides*, and the complexation of soluble Cd, Zn and Cu. Mar. Ecol. Prog. Ser. 2: 143.

Ralph, P.J. and M.D. Burchett. 1998. Photosynthetic response of *Halophila ovalis* to heavy metal stress. Environ. Pollut. 103: 91-101.

Ramachandran, S., T.R. Patel and M.H. Colbo. 1997. Effect of copper and cadmium on three Malaysian tropical estuarine invertebrate larvae. Ecotoxicol. Environ. Safety. 36: 183-188.

Ramamoorthy, S. and K. Blumhagen. 1984. Uptake of Zn, Cd, and Hg by fish in the presence of competing compartments. Can. J. Fish. Aquat. Sci. 41: 750.

Ramesha, A.M., T.R.C. Guptha, R.J. Katti, G. Gowda and C. Lingdhal. 1996. Toxicity of cadmium to common carp *Cyprinus carpio* (Linn.). Environ. Ecol. 14(2): 329-333.

Ramesha, A.M., T.R.C. Gupta, C. Lingdhal, K.V.B. Kumar, G. Gowda and K.S. Udupa. 1997. Combined toxicity of mercury and cadmium to the common carp *Cyprinus carpio* (Linn.) Environ. Ecol. 15(1): 194-198.

Ramirez, P., G. Barrera and C. Rosas. 1989. Effects of chromium and cadmium upon respiration and survival of *Callinectes similis*. Bull. Environ. Contam. Toxicol. 43: 850-857.

Rao, J.I. and M.N. Madhyastha. 1987. Toxicities of some heavy metals to the tadpoles of frog, *Microhyla ornata* (Dumeril and Bibron). Toxicol. Lett. 36: 205-208.

Ray, S., et al. 1981. Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates - a laboratory study. Bull. Environ. Contam. Toxicol. 25: 315.

Rayms-Keller, A., K.E. Olson, M. McGaw, C. Oray, J.O. Carlson and B.J. Beaty. 1998. Effect of heavy metals on *Aedes aegypti* (Diptera: Culicidae) larvae. Ecotoxicol. Environ. Safety. 39: 41-17.

Reader, J.P., N.C. Everall, M.D.J. Sayer and R. Morris. 1989. The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L. J. Fish Biol. 35: 187-198.

Rebhun, S. and A. Ben-Amotz. 1984. The distribution of cadmium between the marine alga *Chlorella stigmatophora* and sea water medium. Water Res. 18(2): 173-179.

Rebhun, S. and A. Ben-Amotz. 1986. Effect of NaCl concentration on cadmium uptake by the halophilic alga *Dunaliella salina*. Mar. Ecol. Prog. Ser. 30: 215-219.

Rebhun, S. and A. Ben-Amotz. 1988. Antagonistic effect of maganese to cadmium toxicity in the alga *Dunaliella salina*. Mar. Ecol. Prog Ser. 42: 97-104.

Reddy, P.S. and M. Fingerman. 1994. Effect of cadmium chloride on amylase activity in the red swamp crayfish, *Procambarus clarkii*. Comp. Biochem. Physiol. 109C(3): 309-314.

Reddy, P.S., S.R. Tuberty and M. Fingerman. 1997. Effects of cadmium and mercury on ovarian maturation in the red swamp crayfish, *Procambarus clarkii*. Ecotoxicol. Environ. Safety. 37: 62-65.

Redmond, M.S., K H. Scott, R.C. Swartz and J.K.P. Jones. 1994. Preliminary culture and life-cycle experiments with the benthic amphipod *Ampelisca abdita*. Environ. Toxicol. Chem. 13(8): 1355-1365.

Rehwoldt, R., et al. 1972. The effect of increased temperature upon the acute toxicity of some heavy metal ions. Bull. Environ. Contam. Toxicol. 8: 91.

Rehwoldt, R., et al. 1973. The acute toxicity of some heavy metals ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10: 291.

Reichert, W.L., et al. 1979. Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 63C: 229.

Reid, S.D. and D.G. McDonald. 1991. Metal binding activity of the gills of rainbow trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 48: 1061-1068.

Reinfelder, J.R. and N.S. Fisher. 1994a. The assimilation of elements ingested by marine planktonic bivalve larvae. Limnol. Oceanogr. 39(1): 12-20.

Reinfelder, J.R. and N.S. Fisher. 1994b. Retention of elements absorbed by juvenile fish (*Menidia menidia*, *Menidia beryllina*) from zooplankton prey. Limnol. Oceanogr. 39(8): 1783-1789.

Reinfelder, J.R., W.X. Wang, S.N. Luoma and N.S. Fisher. 1997. Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels. Mar. Biol. 129: 443-452.

Reish, D.J. 1993. Effects of metals and organic compounds on survival and bioaccumulation in two species of marine gammaridean amphipod, together with a summary of toxicological research on this group. J. Nat.Hist. 27: 781-794.

Reish, D.J. and J.A. LeMay. 1991. Toxicity and bioconcentration of metals and organic compounds by polychaeta. Ophelia Suppl. 5: 653-660.

Reish, D.J., et al. 1976. The effect of heavy metals on laboratory populations of two polychaetes with comparisons to the water quality conditions and standards in Southern California marine waters. Water Res. 10: 299.

Reish, D.J., et al. 1978. Interlaboratory calibration experiments using the Polychaetous annelid *Capitella capitata*. Mar. Environ. Res. 1: 109.

Reish, D.J., S.L. Asato and J.A. Lemay. 1988. The effect of cadmium and DDT on the survival and regeneration in the amphinomid polychaete *Eurythoe complanata*. *In*: Proc. 7th Symp. Mar. Biol., June 1, 1988, LaPaz BCS, Mexico: pp. 107-111.

Remacle, J., et al. 1982. Cadmium fate in bacterial microcosms. Water, Air, Soil Pollut. 18: 455.

Reynoldson, T.B., P.. Rodriguez and M.M Madrid. 1996. A comparison of reproduction, growth and acute toxicity in two populations of *Tubifex tubifex* (Muller, 1774) from the North American great lakes and Northern Spain. Hydrobiol. 334: 199-206.

Rhodes, L., E. Casillas, B. McKnight, W. Gronlund, M. Myers, O.P. Olson and B. McCain. 1985. Interactive effects of cadmium, polychlorinated biphenyls, and fuel oil on experimentally exposed English sole (*Parophrys vetulus*). Can J. Fish. Aquat. Sci. 42: 1870-1880.

Ribo, J.M. 1997. Interlaboratory comparison studies of the luminescent bacteria toxicity bioassay. Environ. Toxicol. Water Qual. 12: 283-294.

Rice, D.L. 1984. A simple mass transport model for metal uptake by marine macroalgae growing at different rates. Exp. Mar. Biol. Ecol. 82: 175-182.

Richelle, E., Y. Degoudenne, L. Dejonghe and G. Van de Vyver. 1995. Experimental and field studies on the effect of selected heavy metals on three freshwater sponge species: *Ephydatia fluviatilis*, *Ephydatia muelleri* and *Spongilla lacustris*. Arch. Hydrobiol. 135(2): 209-231.

Ridlington, J.W., et al. 1981. Metallothionein and Cu-chelation: characterization of metal-binding proteins from the tissues of four marine animals. Comp. Biochem. Physiol. 70B: 93.

Rifici, L.M., D.S. Cherry. J.L. Farris and J. Cairns, Jr. 1996. Acute and subchronic toxicity of methylene blue to larval fathead minnows (*Pimephales promelas*): implications for aquatic toxicity testing. Environ. Toxicol. Chem. 15(8): 1304- 1308.

Riisgard, H.V., E. Bjornestad and F. Mohlenberg. 1987. Accumulation of cadmium in the mussel *Mytilus edulis*: kinetics and importance of uptake via food and sea water. Mar. Biol. 96: 349-353.

Ringwood, A.H. 1989. Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isognomon californicum*, during chronic exposure. Mar. Biol. 102: 499-504.

Ringwood, A.H. 1990. The relative sensitivities of different life stages of *Isognomon californicum* to cadmium toxicity. Arch. Environ. Contam. Toxicol. 19: 338-340.

Ringwood, A.H. 1992a. Comparative sensitivity of gametes and early developmental stages of a sea urchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures. Arch. Environ. Contam. Toxicol. 22: 288-295.

Ringwood, A.H. 1992b. Effects of chronic cadmium exposures on growth of larvae of an Hawaiian bivalve, *Isognomon californicum*. 1992. Mar. Ecol. Prog. Ser. 83: 63-70.

Ringwood, A.H. 1993. Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs. Mar. Environ. Res. 35: 35-39.

Ritterhoff, J., G.P. Zauke and R. Dallinger. 1996. Calibration of the estuarine amphipods, *Gammarus zaddachi* Sexton (1912), as biomonitors: toxicokinetics of cadmium and possible role of inducible metal-binding proteins in Cd detoxification. Aquat. Toxicol. 34: 351-369.

Roberts, K.S., et al. 1979. A high molecular-weight cadmium-binding fraction isolated from the liver cytosol of trout exposed to environmentally relevant concentrations of the metal. Trans. Biochem. Soc. London. 7: 650.

Roch, M. and J.A. McCarter. 1984. Metallothionein induction, growth, and survival of chinook salmon exposed to zinc, copper, and cadmium. Bull. Environ. Contam. Toxicol. 32: 478-485.

Roch, M. and E.J. Maly. 1979. Relationship of cadmium-induced hypocalcemia with mortality in rainbow trout (*Salmo gairdneri*) and the influence of temperature on toxicity. J. Fish. Res. Board Can. 36: 1297.

Roesijadi, G. and G.W. Fellingham. 1987. Influence of Cu, Cd, and Zn preexposure on Hg toxicity in the mussel *Mytilus edulis*. Can. J. Fish. Aquat. Sci. 44: 680-684.

Rombough, P.J. 1985. The influence of the zona radiata on the toxicities of zinc, lead, mercury, copper and silver ions to embryos of steelhead trout *Salmo gairdneri*. Comp. Biochem. Physiol. 82C(1): 115-117.

Rombough, P.J. and E.T. Garside. 1982. Cadmium toxicity and accumulation in eggs and alevins of Atlantic salmon *Salmo salar*. Can. J. Zool. 60: 2006.

Rombough, P.J. and E.T. Garside. 1984. Disturbed ion balance in alevins of Atlantic salmon *Salmo salar* chronically exposed to sublethal concentrations of cadmium. Can. J. Zool. 62: 1443-1450.

Romeo, M. and M. Gnassia-Barelli. 1995. Metal distribution in different tissues and in subcellular fractions of the Mediterranean clam *Ruditapes decussatus* treated with cadmium, copper, or zinc. Comp. Biochem. Physiol. 111C: 457-463.

Rosas, C. and P. Ramirez. 1993. Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* expose to hard and soft water. Bull. Environ. Contam. Toxicol. 51: 568-574.

Roseman, E.F., E.L. Mills, M. Rutzke, W.H. Gutenmann and D.J. Lisk. 1994. Absorption of cadmium from water by North American zebra and quagga mussels (Bivalvia: Dreissenidae). Chemosphere. 28(4): 737-743.

Rosenberg, R. and J.D. Costlow. 1976. Synergistic effects of cadmium and salinity combined with constant and cycling temperatures on the larval development of two estuarine crab species. Mar. Biol. 38: 291.

Rosko, J.J. and J.W. Rachlin. 1977. The effect of cadmium, copper, mercury, zinc and lead on cell division, growth, and chloropyll a content of the chlorophyte *Chlorella vulgaris*. Bull. Torrey Bot. Club 104: 226.

Rouleau, C., M. Block and H. Tjalve. 1998. Kinetics and body distribution of waterborne ^{65}Zn(II), ^{109}Cd(II), ^{203}Hg(II), and $CH_3{}^{203}$Hg(II) in phantom midge larvae (*Chaoborus americanus*) and effects of complexing agents. Environ. Sci. Technol. 32: 1230-1236.

Roux, D.J., P.L. Kempster, E. Truter and L. van der Merwe. 1993. Effect of cadmium and copper on survival and reproduction of *Daphnia pulex*. Water SA. 19(4): 269-274.

Rubinstein, N.I., et al. 1983. Accumulation of PCBs, mercury and cadmium by *Nereis virens*, *Mercenaria mercenaria* and *Palaemontes pugio* from contaminated harbor sediments. Aquat. Toxicol. 3: 249.

Safadi, R.S. 1998. The use of freshwater planarians in acute toxicity test with heavy metals. Verh. Internat. Verein. Limnol. 26: 2391-2392

Sajwan, K.S. and W.H. Ornes. 1994. Phytoavailability and bioaccumulation of cadmium in duckweed plants (*Spirodela polyrhiza* L. Schleid). J. Environ. Sci. Health. A29(5): 1035-1044.

Sanchiz, C., A.M. Garcia-Carrascosa and A. Pastor. 1999. Bioaccumulation of Hg, Cd, Pb and Zn in four marine phanerogams and the alga *Caulerpa prolifera* (Forsskal) Lamouroux from the east coast of Spain. Bot. Mar. 42(2): 157-164.

Sandau, E., P. Sandau and O. Pulz. 1996. Heavy metal sorption by microalagae. Acta Biotechnol. 16(4): 227-235.

Sangalang, G.B. and H.C. Freeman. 1979. Tissue uptake of cadmium in brook trout during chronic sublethal exposure. Arch. Environ. Contam. Toxicol. 8: 77.

Sangalang, G.B. and M.J. O'Halloran. 1972. Cadmium-induced testicular injury and alterations of androgen synthesis in brook trout. Nature 240: 470.

Sangalang, G.B. and M.J. O'Halloran. 1973. Adverse effects of cadmium on brook trout testis and on *in vitro* testicular androgen synthesis. Biol. Reprod. 9:394.

Santiago-Fandino, V.J.R. 1983. The effects of nickel and cadmium on the growth rate of *Hydra littoralis* and an assessment of the rate of uptake of ^{63}Ni and ^{14}C by the same organism. Water Res. 17: 917.

Santojanni, A., G. Gorbi and F. Sartore. 1998. Prediction of fecundity in chronic toxicity tests on *Daphnia magna*. Water Res. 32(1): 3146-3156.

Sastry, K.V. and V. Shukla. 1994. Influence of protective agents in the toxicity of cadmium to a freshwater fish (*Channa punctatus*). Bull. Environ. Contam. Toxicol. 53: 711-717.

Sastry, K.V. and K. Sunita. 1982. Effect of cadmium and chromium on the intestinal absorption of glucose in the snakehead fish, *Channa punctatus*. Toxicol. Letters. 10: 293.

Sauter, S., et al. 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and fry of seven fish species. EPA-600/3-76-105. National Technical Information Service, Springfield, Virginia.

Sauvant, M.P., D. Pepin, C.A. Groliere and J. Bohatier. 1995. Effects of organic and inorganic substances on the cell proliferation of L-929 *Fibroblasts* and *Tetrahymena* toxicological bioassays. Bull. Environ. Contam. Toxicol. 55: 171-178.

Sauvant, M.P., D. Pepin, J. Bohatier, C.A. Groliere and J. Guillot. 1997. Toxicity assessment of 16 inorganic environmental pollutants by six bioassays. Ecotoxicol. Environ. Safety. 37: 131-140.

Saxena, K.K., A.K. Dubey and R.R.S. Chauhan. 1993. Experimental studies on toxicity of zinc and cadmium to *Heteropneustes fossilis* (Bl.) J. Freshwater Biol. 5(4): 343-346.

Schaeffer, D.J., M. Goehner, E. Grebe, L.G. Hansen, K. Hankenson, E.E. Herricks, G. Matheus, A. Miz, R. Reddy and K. Trommater. 1991. Evaluation of the "reference toxicant" addition procedure for testing the toxicity of environmental samples. Bull. Environ. Contam. Toxicol. 47: 540-546.

Schafer, H., A. Wenzel, U. Fritsche, G. Roderer and W. Traunspurger. 1993. Long-term effects of selected xenobiotica on freshwater green algae: development of a flow-through test system. Sci.Total Environ., Supplemental Part 1: 735-740.

Schafer, H., H. Hettler, U. Fritsche, G. Pitzen, G. Roderer and A. Wenzel. 1994. Biotests using unicellular algae and ciliates for predicting long-term effects of toxicants. Ecotoxicol. Environ. Safety. 27: 64-81.

Scherer, E., R.E. McNicol and R.E. Evans. 1997. Impairment of lake trout foraging by chronic exposure to cadmium: a black-box experiment. Aquat. Toxicol. 37: 1-7.

Schubauer-Berigan, M.K., J.R. Dierkes, P.D. Monson and G.T. Ankley. 1993. pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to *Ceriodaphnia dubia*, *Pimephales promelas*, *Hyalella azteca* and *Lumbriculus variegatus*. Environ. Toxicol. Chem. 12: 1261-1266.

Schuster, C.N. and B.H. Pringle. 1969. Trace metal accumulation by the American oyster, *Crassostrea virginica*. Proc. Natl. Shellfish Assoc. 59: 91.

Scott, K.J., et al. Manuscript. Toxicological methods using the benthic amphipod *Ampelisca abdita* Mills. U.S. EPA, Narragansett, Rhode Island.

Sedlacek, J., E.T. Gjessing and T. Kallqvist. 1989. Influence of different aquatic humus fractions on uptake of cadmium to alga *Selenastrum capriconutum* Printz. Sci. Total Environ. 81/82: 711-718.

Sehgal, R. and A.B. Saxena. 1987. Determination of acute toxicity levels of cadmium and lead to the fish *Lebistes reticulatus* (Peters). Int. J. Environ. Stud. 29: 157-161.

Sekkat, N., A. Le Du, J.M. Jouany and M. Guerbet. 1992. Study of the interactions between copper, cadmium, and ferbam using the protozoan *Colpidium campylum* bioassay. Ecotoxicol. Environ. Safety. 24: 294-300.

Selby, D.A., J.M. Ihnat and J.J. Messer. 1985. Effects of subacute cadmium exposure on a hardwater mountain stream microcosm. Water Res. 19(5): 645-655.

Servizi, J.A. and D.W. Martens. 1978. Effects of selected heavy metals on early life of sockeye and pink salmon. International Pacific Salmon Fisheries Commission, Progress Report No. 39, New Westminster, B.C. Canada.

Seyfreid, P.L. and C.B.L. Horgan. 1983. Effect of cadmium on lake water bacteria as determined by the luciferase assay of adenosine triphosphate. *In:* W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802, American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 425.

Shanmukhappa, H. and K. Neelakantan. 1990. Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular alga, *Synechosystis aquatilis*. Bull. Environ. Contam. Toxicol. 44: 840-843.

Sharma, M.S. and C.S. Selvaraj. 1994. Zinc, lead and cadmium toxicity to selected freshwater zooplankters. Pollut. Res. 13(2): 191-201.

Sharp, J.R. and J.L. Kaszubski. 1989. The influence of exposure duration on the embryotoxicity of cadmium to the freshwater teleost, *Etheostoma spectabile*. Trace Subst. Environ. Health. 23: 277-289.

Shazili, N.A.M. and D. Pascoe. 1986. Variable sensitivity of rainbow trout (*Salmo gairdneri*) eggs and alevins to heavy metals. Bull. Environ. Contam. Toxicol. 36: 468-474.

Shcherban, E.P. 1977. Toxicity of some heavy metals for *Daphnia magna* Strauss, as a function of temperature. Hydrobiol. 13(4): 75.

Sheela, M., G. Mallika and S. Muniandy. 1995. Impact of cadmium on food utilization, growth and body composition in the fish *Oreochromis mossambicus*. Environ. Ecol. 13(2): 410-414.

Sherman, R.E., S.P. Gloss and L.W. Lion. 1987. A comparison of toxicity test conducted in the laboratory and in experimental ponds using cadmium and the fathead minnow (*Pimephales promelas*). Water Res. 21(3): 317-323.

Shivaraj, K.M. and H.S. Patil. 1988. Toxicity of cadmium and copper to a freshwater fish *Puntius arulius*. Environ. Ecol. 6(1): 5-8

Shukla, J.P. and K. Pandey. 1988. Toxicity and long term effects of a sublethal concentration of cadmium on the growth of the fingerlings of *Ophiocephalus punctatus* (Bl.). Acta Hydrochim. Hydrobiol. 16(5): 537-540.

Sick, L.V. and G. Baptist. 1979. Cadmium incorporation by the marine copepod *Pseudodiaptomous coronatus*. Limnol. Oceanogr. 24: 453.

Sidoumou, Z., M. Gnassia-Barelli and M. Romeo. 1997. Cadmium and calcium uptake in the mollusc *Donax rugosus* and effect of a calcium channel blocker. Bull. Environ. Contam. Toxicol. 58: 318-325.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena and M.A. Sampayo. 1988. Effect of nutrients, temperature and light on uptake of cadmium by *Selenastrum capricornutum* Printz. Water Res. 22(11): 1429-1435.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena, L.M.V.F. Machado, C.M.R. Pescada and M.L. de Moura. 1989. Effect of speciation on uptake and toxicity of cadmium to shrimp *Crangon crangon* (L.). Bull. Environ. Contam. Toxicol. 43: 287-294.

Sinha, S, M. Gupta and P. Chandra. 1994. Bioaccumulation and toxicity of Cu and Cd in *Vallisneria spiralis* (L.). Environ. Monit. Assess. 33(1): 75-84.

Skowronski, T. and M. Przytocka-Jusiak. 1986. Cadmium removal by green alga *Stichococcus bacillaris*. Chemosphere. 15(1): 77-79.

Skowronski, T., M. Jakubowski and B. Pawlik. 1985. Cadmium toxicity to green alga *Stichococcus bacillaris*. Acta Microbiol. Polonica. 34(3/4): 309.

Skowronski, T., B. Pawlik and M. Jakubowski. 1988. Reduction of cadmium toxicity to green microalga *Stichococcus bacillaris* by manganese. Bull. Environ. Contam. Toxicol. 41: 915-920.

Skowronski, T., S. Szubinska, B. Pawlik, M. Jakubowski, R. Bilewicz and E. Cukrowsak. 1991. The influence of pH on cadmium toxicity to the green alga *Stichococcus bacillaris* and on the cadmium forms present in the culture medium. Environ. Pollut. 74: 89-100.

Sloof, J.E., A. Viragh and B. Van der Veer. 1995. Kinetics of cadmium uptake by green algae. Water, Air, Soil Pollut. 83: 105-122.

Slooff, W. 1983. Benthic macroinvertebrates and water quality assessment: some toxicological considerations. Aquat. Toxicol. 4: 73.

Slooff, W. and R. Baerselman. 1980. Comparison of the usefulness of the Mexican axoloth (*Ambystoma mexicanum*) and the clawed toad (*Xenopus laevis*) in toxicological bioassays. Bull. Environ. Contam. Toxicol. 24: 439.

Slooff, W.J., et al. 1983. Comparison of the susceptibility of 22 freshwater species to 15 chemical compounds. I. (sub)acute toxicity tests. Aquat. Toxicol. 4: 113.

Smith, D.P., J.H. Kennedy and K.L. Dickson. 1991. An evaluation of a naidid oligochaete as a toxicity test organism. Environ. Toxicol. Chem. 10: 1459-1465.

Smith, J.D., et al. 1981. Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem. Aust. J. Mar. Freshwater Res. 32: 151.

Smith, S. and M.K.H. Kwan. 1989. Use of aquatic macrophytes as a bioassay method to assess relative toxicity, uptake and accumulated forms of trace metals. Hydrobiol. 188/189: 345-351.

Smokorowski, K.E., D.C. Lasenby and R.D. Evans. 1998. Quantifying the uptake and release of cadmium and copper by the opossum shrimp *Mysis relicta* preying upon the cladoceran *Daphnia magna* using stable isotope tracers. Can. J. Fish. Aquat. Sci. 55: 909-915.

Snell, T.W. and M.J. Carmona. 1995. Comparative toxicant sensitivity of sexual and asexual reproduction in the rotifer *Brachionus calyciflorus*. Environ. Toxicol. Chem. 14: 415-420.

Snell, T.W. and B.D. Moffat. 1992. A 2-d life cycle test with the rotifer *Brachionus calyciflorus*. Environ. Toxicol. Chem. 11: 1249-1257.

Snell, T.W. and G. Persoone. 1989a. Acute toxicity bioassays using rotifers. I. A test for brackish and marine environments with *Brachionus plicatilis*. Aquat. Toxicol. 14: 65-80.

Snell, T.W. and G. Persoone. 1989b. Acute toxicity bioassays using rotifers. II. A freshwater test with *Brachionus rubens*. Aquat. Toxicol. 14: 81-92.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991a. Acute toxicity test using rotifers. III. Effects of temperature, strain and exposure time on the sensitivity of *Brachionus plicatilis*. Environ. Toxicol. Water Quality. 6: 63-75.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991b. Acute toxicity tests using rotifers. Ecotoxicol. Environ. Safety. 21: 308-317.

Sobahn, R. and S.P.K. Sternberg. 1999. Cadmium removal using cladophora. J. Environ. Sci. Health. A34(1): 53-72.

Sorvari, J. and M. Sillanpaa. 1996. Influence of metal complex formation on heavy metal and free EDTA and DTPA acute toxicity determined by *Daphnia magna*. Chemosphere. 33(6): 1119-1127.

Sosnowski, S. and J. Gentile. 1978. Toxicological comparison of natural and cultured populations of *Acartia tonsa* to cadmium, copper and mercury. J. Fish. Res. Board Can. 35: 1366.

Sovenyi, J. and J. Szakolczai. 1993. Studies on the toxic and immunosuppressive effects of cadmium on the common carp. Acta Veterinaria Hungarica. 41(3-4): 415-426.

Spehar, R.L. 1976a. Cadmium and zinc toxicity to flagfish, *Jordanella floridae*. J. Fish. Res. Board Can. 33: 1939.

Spehar, R.L. 1976b. Cadmium and zinc toxicity to *Jordanella floridae*. EPA-600/3-76-096. National Technical Information Service, Springfield, Virginia.

Spehar, R.L. 1982. Memorandum to J.G. Eaton. U.S. EPA, Duluth, Minnesota. February 24.

Spehar, R.L. and A.R. Carlson. 1984a. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. PB84-153196. National Technical Information Service, Springfield, Virginia.

Spehar, R.L. and A.R. Carlson. 1984b. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. Environ. Toxicol. Chem. 3: 651.

Spehar, R.L. and J.T. Fiandt. 1986. Acute and chronic effects of water quality criteria-based metal mixtures on three aquatic species. Environ. Toxicol. Chem. 5: 917-931.

Spehar, R.L., et al. 1978. Toxicity and bioaccumulation of cadmium and lead in aquatic invertebrates. Environ. Pollut. 15: 195.

Sprague, J.B. 1985. Factors that modify toxicity. *In:* Fundamentals of aquatic toxicology. Rand, G.M. and S.R. Petrocelli (eds.). Hemisphere Publishing Company, New York, N.Y. pp.124-163.

Spry, D.J. and J.G. Wiener. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: a critical review. Environ. Pollut. 243-304.

Srivastava, A. and K.J. Appenroth. 1995. Interaction of EDTA and iron on the accumulation of Cd^{2+} in duckweeds (Lemnaceae). J. Plant Physiol. 146: 173-176.

Stackhouse, R.A. and W.H. Benson. 1988. The influence of humic acid on the toxicity and bioavailability of selected trace metals. Aquat. Toxicol. 13: 99-108.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (*Myriophyllum spicatum* L.). Arch. Environ. Contam. Toxicol. 2: 331.

Stary, J. and K. Kratzer. 1982. The cumulation of toxic metals on alga. Int. J. Environ. Anal. Chem. 12: 65.

Stary, J., et al. 1982. The cumulation of zinc and cadmium in fish (*Poecilia reticulata*). Int. J. Environ. Anal. Chem. 11: 117.

Stary, J., et al. 1983. Cumulation of zinc, cadmium and mercury on the alga *Scenedesmus obliquus*. Acta. Hydrochim. Hydrobiol. 11: 401.

Stebbing, A.R.D. 1976. The effects of low metal levels on a colonial hydroid. J. Mar. Biol. Assoc. U.K. 56: 1977.

Steele, R.L. and G.B. Thursby. 1983. A toxicity test using life stages of *Champia parvula* (Rhodophyta). *In:* W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 73.

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. National Technical Information Service, Springfield, Virginia. 98 pp.

Stephan, C.E. 1995. Derivation of conversion factors for the calculation of dissolved freshwater aquatic life criteria for metals. U.S. Environmental Protection Agency, Environmental Research Lab- Duluth, MN. 35 pp.

Stephenson, M. and G.L. Macki. 1989. Net cadmium flux in *Hyalella azteca* (Crustacea: Amphipoda) populations from five central Ontario lakes. Sci. Total Environ. 87/88: 463-475.

Stephenson, M. and M.A. Turner. 1993. A field study of cadmium dynamics in periphyton and in *Hyalella azteca* (Crustacea: amphipoda). Water, Air, Soil Pollut. 68: 341-361.

Stern, M.S. and D.H. Stern. 1980. Effects of fly ash heavy metals on *Daphnia magna*. PB81-198327. National Technical Information Service, Springfield, Virginia.

Stom, D.I. and L.D. Zubareva. 1994. Comparative resistance of *Daphnia* and *Epischura* to toxic substances in acute exposure. Hydrobiol. 30(3): 35-38.

Stratus Consulting, Inc. 1999. Sensitivity of bull trout (*Salvelinus confluentus*) to cadmium and zinc in water characteristic of the Coeur D'Alene River Basin: acute toxicity report. Final Report to U.S. EPA Region X. 55 pp.

Stromberg, P.C., et al. 1983. Pathology of lethal and sublethal exposure of fathead minnows, *Pimephales promelas*, to cadmium: a model for aquatic toxicity assessment. J. Toxicol. Environ. Health 11: 247.

Stuhlbacher, A. and L. Maltby. 1992. Cadmium resistance in *Gammarus pulex* (l.). Arch. Environ. Contam. Toxicol. 22: 319-324.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1992. Induction of cadmium tolerance in two clones of *Daphnia magna* Straus. Comp. Biochem. Physiol. 101C(3): 571-577.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1993. Variation in the development of cadmium resistance in *Daphnia magna* Straus; effect of temperature, nutrition, age and genotype. Environ. Pollut. 80(2): 153-158.

Sullivan, B.K., et al. 1983. Effects of copper and cadmium on growth, swimming and predator avoidance in *Eurytemora affinis* (Copepoda). Mar. Biol. 77: 299.

Sunda, W.G. and S.A. Huntsman. 1996. Antagonisms between cadmium and zinc toxicity and manganese limitation in a coastal diatom. Limnol. Oceanogr. 41(3): 373-387.

Sunda, W.G., et al. 1978. Effect of chemical speciation on toxicity of cadmium to grass shrimp, *Palaemonetes pugio*: importance of free cadmium ion. Environ. Sci. Technol. 12: 409.

Sunderman, F.W., Jr., M.C. Plowman and S.M. Hopfer. 1991. Embryotoxicity and teratogenicity of cadmium chloride in *Xenopus laevis*, assayed by the FETAX procedure. Ann. Clin. Lab. Sci. 21(6): 381-391.

Sunil, P.P.G, N. Siriwardena, K.J. Rana and D.J. Baird. 1995. A method for partitioning cadmium bioaccumulated in small aquatic organisms. Environ. Toxicol. Chem. 14(9): 1575-1577.

Sunila, I. and R. Lindstrom. 1985. Survival, growth and shell deformities of copper- and cadmium-exposed mussels (*Mytilus edulis* L.) in brackish water. Estuarine Coastal Shelf Sci. 21(4): 555-565.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993a. Effect of lethal and sublethal concentrations of cadmium on energetics in the gills of fry and fingerlings of *Cyprinus carpio*. Bull. Environ. Contam. Toxicol. 51: 920-926.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993b. Patterns of cadmium accumulation in the organs of fry and fingerlings of freshwater fish *Cyprinus carpio* following cadmium exposure. Chemosphere. 26(5): 945-953.

Suzuki, K.T., H. Sunaga, E. Kobayashi and S. Hatakeyama. 1987. Environmental and injected cadmium are sequestered by two major isoforms of basal copper, zinc-metallothionein in gibel (*Carassius auratus langsdorfi*) liver. Comp. Biochem. Physiol. 87C(1): 87-93.

Swinehart, J.H. 1990. Final Technical Report for U.S.G.S. Grant: The effects of humic substances on the interactions of metal ions with organisms and liposomes. Department of Chemistry, University of California, Davis, CA 95616: 103 pp.

Takamura, N., F. Kasai and M.M. Watanabe. 1989. Effects of Cu, Cd and Zn on photosynthesis of freshwater benthic algae. J. Appl. Phycol. 1: 39-52.

Talbot, V. 1985. Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*. Mar. Biol. 85: 51-54.

Talbot, V. 1987. Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: A water-quality criterion. Mar. Biol. 94: 557-560.

Taraldsen, J.E. and T.J. Norberg-King. 1990. New method for determining effluent toxicity using duckweed (*Lemna minor*). Environ. Toxicol. Chem. 9: 761-767.

Tarzwell, C.M. and C. Henderson. 1960. Toxicity of less common metals to fishes. Ind. Wastes 5: 12.

Taylor, G., D.J. Baird and A.M.V.M. Soares. 1998. Surface binding of contaminants by algae: consequences for lethal toxicity and feeding to *Daphnia magna* Straus. Environ. Toxicol. Chem. 17(3): 412-419.

Temara, A., G. Ledent, M. Warnau, H. Paucot, M. Jangoux and P. Dubois. 1996a. Experimental cadmium contamination of *Asterias rubens* (Echinodermata). Mar. Ecol. Prog. Ser. 140: 83-90.

Temara, A., M. Warnau, G. Ledent, M. Jangoux and P. Dubois. 1996b. Allometric variations in heavy metal bioconcentration in the asteroid *Asterias rubens* (Echinodermata). Bull. Environ. Contam. Toxicol. 56: 98-105.

Ten Hoopen, H.J.G., P.J. Nobel, A. Schaap, A. Fuchs and J.A. Roels. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. I. Development of cadmium tolerance in batch cultures. Antonie van Leeuwenhoek. 51: 344-346.

Tessier, A., Y. Couillard, P.G.C. Campbell and J.C. Auclair. 1993. Modeling Cd partitioning in oxic lake sediments and Cd concentrations in the freshwater bivalve *Anodonta grandis*. Limnol Oceanogr. 38(1): 1-17.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994a. Comparative study of the cadmium and mercury kinetics between the short-lived gastropod *Viviparus georgianus* (lea) and pelecypod *Elliptio complanata* (lightfoot), under laboratory conditions. Environ. Pollut. 85: 271-282.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994b. Temperature effects on cadmium and mercury kinetics in freshwater molluscs under laboratory conditions. Arch. Environ. Contam. Toxicol. 26:179-184.

Tessier, L. G. Vaillancourt and L. Pazdernik. 1996. Laboratory study of Cd and Hg uptake by two freshwater molluscs in relation to concentration, age and exposure time. Water, Air, Soil Pollut. 86: 347-357.

Thaker, A.A. and A.A. Haritos. 1989. Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*. Comp. Biochem. Physiol. 94C(1): 63-70.

Thebault, M.T., A. Biegniewska, J.P. Raffin and E.F. Skorkowski. 1996. Short term cadmium intoxication of the shrimp *Palaemon serratus*: effect on adenylate metabolism. Comp. Biochem. Physiol. 113C(3): 345-348.

Theede, H., et al. 1979. Temperature and salinity effects on the acute toxicity of cadmium to *Laomedea loveni* (Hydrozoa). Mar. Ecol. Prog. Ser. 1:13.

Thellen, C., C. Blaise, Y. Roy and C. Hickey. 1989. Round robin testing with the *Selenastrum capricornutum* microplate toxicity assay. Hydrobiol. 188/189: 259-268.

Thomann, R.V., F. Shkreli and S. Harrison. 1997. A pharmacokinetic model of cadmium in rainbow trout. Environ. Toxicol. Chem. 16(11): 2268-2274.

Thomas, D.G., A. Cryer, J.F. Del G. Solbe and J. Kay. 1983. A comparison of the accumulation and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson). Comp. Biochem. Physiol. 76C(2): 241-246.

Thomas, D.G., M.W. Brown, D. Shurben, J.F. Del G. Solbe, A. Cryer and J. Kay. 1985. A comparison of the sequestration of cadmium and zinc in the tissues of rainbow trout (*Salmo gairdneri*) following exposure to the metals singly or in combination. Comp. Biochem. Physiol. 82C(1): 55-62.

Thompson, P.A. and P. Couture. 1991. Short- and long-term changes in growth and biochemical composition of *Selenastrum capricornutum* populations exposed to cadmium. Aquat. Toxicol. 21: 135-144.

Thompson, S.E., et al. 1972. Concentration factors of the chemical elements in edible aquatic organisms. UCRL-50564. Rev. 1. National Technical Information Service, Springfield, Virginia.

Thongra-ar, W. and O. Matsuda. 1995. Effects of cadmium and zinc on growth of *Thalassiosira weissflogii* and *Heterosigma akiashiwo*. *In*: A. Snidvongs, W. Utoomprukporn and M. Hungspreugs (eds.), 1995, Proceedings of the NRCT-JSPS Joint Seminar on Marine Science, December 2-3, 1993, Chulalongkorn University, Songkhla, Thailand. Bangkok: Department of Marine Science: pp. 90-96.

Thorp, J.H. and S.P. Gloss. 1986. Field and laboratory tests on acute toxicity of cadmium to freshwater crayfish. Bull. Environ. Contam. Toxicol. 37: 355-361.

Thorp, J.H., et al. 1979. Effects of chronic cadmium exposure on crayfish survival, growth, and tolerance to elevated temperatures. Arch. Environ. Contam. Toxicol. 8: 449.

Thorpe, G.J. and J.D. Costlow. 1989. The relation of the acute (96-h) uptake and subcellular distribution of cadmium and zinc to cadmium toxicity in larvae of *Rhithropanopeus harrisii* and a *Palaemonetes pugio*. *In:* U.M. Cowgill and L.R. Williams (eds.), Aquatic Toxicology and Hazard Assessment, ASTM STP 1027, Philadelphia, PA. 12: 82-94.

Thursby, G.B. and R.L. Steele. 1986. Comparison of short- and long-term sexual reproduction tests with the marine red alga *Champia Parvula*. Environ. Toxicol. Chem. 5: 1013-1018.

Timmermans, K.R., W. Peeters and M. Tonkes. 1992. Cadmium, zinc, lead and copper in *Chironomus riparius* (Meigen) larvae (Diptera, Chironomidae): uptake and effects. Hydrobiol. 241: 119-134.

Tomasik, P., C.M. Magadza, S. Mhizha and A. Chirume. 1995a. The metal-metal interactions in biological systems. Part III. *Daphnia magna*. Water, Air, Soil Pollut. 82: 695-711.

Tomasik, P, C.M. Magadza, S. Mhizha, A. Chirume, M.F. Zaranyika and S. Muchiriri. 1995b. Metal-metal interaction in biological systems. Part IV. Freshwater snail *Bulinus globosus*. Water, Air, Soil Pollut. 83: 123-145.

Torres, E., A. Cid, C. Herrero and J. Abalde. 1998. Removal of cadmium ions by the marine diatom *Phaeodactylum tricornutum* Bohlin accumulation and long-term kinetics of uptake. Bioresource Techn. 63: 213-220.

Tortell, P.D. and N.M. Price. 1996. Cadmium toxicity and zinc limitation in centric diatoms of the genus *Thalassiosira*. Mar. Ecol. Prog. Ser. 138: 245-254.

Toudal, K. and H.U. Riisgard. 1987. Acute and sublethal effects of cadmium on ingestion, egg production and life-cycle development in the copepod *Acartia tonsa*. Mar. Ecol. Prog. Ser. 37: 141-146.

Toussaint, M.W., T.R. Shedd, W.H. Van der Schalie and G.R. Leather. 1995. A comparison of standard acute toxicity test with rapid-screening toxicity test. Environ. Toxicol. Chem. 14(5): 907-915.

Trehan, K. and Maneesha. 1994. Cadmium mediated control of nitrogenase activity and other enzymes in a nitrogen fixing cyanobacterium. Acta Microbiol. Hungarica. 41(4): 441-449.

Trevors, J.T., G.W. Stratton and G.M. Gadd. 1986. Cadmium transport, resistance, and toxicity in bacteria, algae, and fungi. Can. J. Microbiol. 32: 447-464.

Tucker, R.K. 1979. Effects of in vivo cadmium exposure on ATPases in gill of the lobster, *Homarus americanus*. Bull. Environ. Contam. Toxicol. 23: 33.

Tucker, R.K. and A. Matte. 1980. In vitro effects of cadmium and lead on ATPases in the gill of the rock crab, *Cancer irroratus*. Bull. Environ. Contam. Toxicol. 24: 847.

Twagilimana, L., J. Bohatier, C. Groliere, F. Bonnemoy and D. Sargos. 1998. A new low-cost microbiotest with the protozoan *Spirostomum teres*: culture conditions and assessment of sensitivity of the ciliate to 14 pure chemicals. Ecotoxicol. Environ. Safety. 41: 231-244.

Tyurin, A.N. and N.K. Khristoforova. 1993. Effect of toxicants on the development of the chiton *Ischnochiton hakodadensis*. Russ. Mar. Biol. 29(5/6): 100-106.

Udoidiong, O.M. and P.M. Akpan. 1991. Toxicity of cadmium, lead and lindane to *Egeria radiata* Lamarck (Lamellibranchia, Donacidae). Rev. Hydrobiol. Trap. 24(2): 111-117.

University of Wisconsin - Superior. 1995. Results of freshwater simulation tests concerning dissolved metal. Final Report to U.S. EPA. ERL- Duluth, MN. 93 pp.

U.S. EPA. 1976. Quality criteria for water. EPA-440/9-76-023. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1980. Ambient water quality criteria for cadmium. EPA-440/5-80-025. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983a. Methods for chemical analysis of water and wastes. EPA-600/4-79-020 (Revised March 1983). National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983b. Water quality standards regulation. Federal Register 48: 51400. November 8.

U.S. EPA. 1983c. Water quality standards handbook. Office of Water Regulations and Standards, Washington, D.C.

U.S. EPA. 1985. Ambient water quality criteria for cadmium. EPA-440/5-84-032 (Revised late 1984). National Technical Information Service, Springfield , VA. 127 pp.

U.S. EPA. 1991. Technical support document for water quality-based toxics control. EPA-505/2-90-001. Office of Water, Washington, D.C.

U.S. EPA. 1993. Water quality criteria: Aquatic life criteria for metals. Federal Register. 58(108): 32131-32133.

U.S. EPA. 1994a. Water quality standards handbook, second ed. EPA-823-B-94-005b. Office of Water, Washington, D.C.

U.S. EPA. 1994b. Interim guidance on determination and use of water-effect ratios for metals. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA-823-B-94-001

U.S. EPA. 1996. 1995 Updates: Water quality criteria documents for the protection of aquatic life in water. U.S. EPA, Office of Water. EPA-820-B-96-001.

U.S. EPA. 1999a. National Recommended Water Quality Criteria -- Correction. EPA-822-Z-99-001. Office of Water, Washington, D.C.

U.S. EPA. 1999b. Integrated approach to assessing the bioavailability and toxicity of metals in surface water and sediments. EPA-822-E-99-001. Office of Water, Washington, D.C.

U.S. EPA. 2000. A SAB Report: Review of the biotic ligand model of the acute toxicity of metals. U.S. Environmental Protection Agency. Washington, D.C. EPA-SAB-EPEC-00-006. 15 pp.

Uthe, J.F., et al. 1982. Cadmium in American lobster (*Homarus americanus*) from the area of a lead smelter. Can. Tech. Rept. Fish. Aquat. Sci. No. 1163.

Valencia, R., M. Gerpe, J. Trimmer, T. Buckman, A.Z. Mason and P.E. Olsson. 1998. The effect of estrogen on cadmium distribution in rainbow trout (*Oncorhynchus mykiss*). Mar. Environ. Res. 46(1-5): 167-171.

Van den Hurk, P., M. Faisal and M.H. Roberts Jr. 1998. Interaction of cadmium and benzo[a]pyrene in mummichog (*Fundulus heteroclitus*): effects on acute mortality. Mar. Environ. Res. 46(1-5): 525-528.

Van der Heever, J.A. and J.U. Grobbelaar. 1996. The use of *Selenastrum capricornutum* growth potential as a measure of toxicity of a few selected compounds. Water SA 22(2): 183-191.

Van Gemert, J.M, H.J.G. Ten Hoopen, J.A. Roels and A. Fuchs. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. II. Light-limited growth in continuous culture. Antonie van Leeuwenhoek. 51: 347-351.

Van Ginneken, L., M.J. Chowdhury and R. Blust. 1999. Bioavailability of cadmium and zinc to the common carp, *Cyprinus carpio*, in complexing environments: A test for the validity of the free ion activity model. Environ. Toxicol. Chem. 18(10): 2295-2304.

Van Leeuwen, C.J., P.S. Griffioen, W.H.A. Vergouw and J.L. Maas-Diepeveen. 1985a. Differences in susceptibility of early life stages of rainbow trout (*Salmo gairdneri*) to environmental pollutants. Aquat. Toxicol. 7: 59-78.

Van Leeuwen, C.J., W.J. Luttmer and P.S. Griffioen. 1985b. The use of cohorts and populations in chronic toxicity studies with *Daphnia magna*: a cadmium example. Ecotoxicol. Environ. Safety. 9: 26-39.

Van Leeuwen, C.J., G. Niebeek and M. Rijkeboer. 1987. Effects of chemical stress on the population dynamics of *Daphnia magna*: a comparison of two test procedures. Ecotoxicol. Environ. Safety. 14:1-11.

Van Steveninck, R.F.M., M.E. Van Steveninck and D.R. Fernando. 1992. Heavy-metal (Zn, Cd) tolerance in selected clones of duck weed (*Lemna minor*). Plant Soil. 146: 271-280.

Vanegas, C., S. Espina, A.V. Botello and S. Villanueva. 1997. Acute toxicity and synergism of cadmium and zinc in white shrimp, *Penaeus setiferus*, juveniles. Bull. Environ. Contam. Toxicol. 58: 87-92.

Vashchenko, M.A. and P.M. Zhadan. 1993. Ecological assessment of marine environment using two sea urchin tests. disturbance of reproduction and sediment embryotoxicity. Sci. Total Environ. Supplemental Part 2: 1235-1245.

Vasseur, P and P. Pandard. 1988. Influence of some experimental factors on metals toxicity to *Selenastrum capricornutum*. Toxic. Assess. 3: 331-343.

Veldhuizen-Tsoerkan, M.B., D.A. Holwerda and D.I. Zandee. 1991. Anoxic survival time and metabolic parameters as stress indices in sea mussels exposed to cadmium or polychlorinated biphenyls. Arch. Environ. Contam. Toxicol. 20: 259-265.

Verbost, P.M., G. Flik, R.A.C. Lock and S.E.W. Bonga. 1987. Cadmium inhibition of Ca^{2+} uptake in rainbow trout gills. Am. J. Physiol. 253 (Regulatory Integrative Comp. Physiol. 22): R216-R221.

Verma, S.R., et al. 1980. Short term toxicity tests with heavy metals for predicting safe concentrations. Toxicol. Letters 1: 113.

Vernberg, W.B., et al. 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, *Uca pugilator*. *In:* F.J. Vernberg and W.B. Vernberg (eds.), Pollution and Physiology of Marine Organisms. Academic Press, New York. p. 381.

Vernberg, W.B., et al. 1977. Effects of sublethal concentrations of cadmium on adult *Paleomonetes pugio* under static and flow-through conditions. Bull. Environ. Contam. Toxicol. 17: 16.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1981. Effects of some environmental factors on the toxicity of cadmium to the copepod *Tisbe holothuriae*. Arch. Hydrobiol. 91: 287.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1982. Differentiation of the sensitivity to copper and cadmium in different life stages of a copepod. Mar. Pollut. Bull. 13: 123.

Versteeg, D.J. 1990. Comparison of short- and long-term toxicity test results for the green alga, *Selenastrum capricornutum*. *In:* Plants for Toxicity Assessment. ASTM STP 1091. W. Wang, J.W. Gorsuch and W.R. Lower (eds), American Society for Testing and Materials, Philadelphia. pp. 40-48.

Visviki, I. and J.W. Rachlin. 1991. The toxic action and interactions of copper and cadmium to the marine alga *Dunaliella minuta*, in both acute and chronic exposure. Arch. Environ. Contam. Toxicol. 20: 271-275.

Visviki, I. and J.W. Rachlin. 1994. Acute and chronic exposure of *Dunaliella salina* and *Chlamydomonas bullosa* to copper and cadmium: effects on growth. Arch. Environ. Contam. Toxicol. 26: 149-153.

Vogiatzis, A.K. and N.S. Loumbourdis. 1998. Cadmium accumulation in liver and kidneys and hepatic metallothionein and glutathione levels in *Rana ridibunda*, after exposure to $CdCl_2$. Arch. Environ. Contam. Toxicol. 34: 64-68.

Voyer, R.A. 1975. Effect of dissolved oxygen concentration on the acute toxicity of cadmium to the mummichog, *Fundulus heteroclitus*. Trans. Am. Fish. Soc. 104: 129.

Voyer, R.A. and D.G. McGovern. 1991. Influence of constant and fluctuating salinity on responses of *Mysidopsis bahia* exposed to cadmium in a life-cycle test. Aquat. Toxicol. 19: 215-230.

Voyer, R.A. and G. Modica. 1990. Influence of salinity and temperature on acute toxicity of cadmium to *Mysidopsis bahia* Molenock. Arch. Environ. Contam. Toxicol. 19: 124-131.

Voyer, R.A., et al. 1977. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to combinations of cadmium and salinity at selected temperatures. Mar. Biol. 44: 117.

Voyer, R.A., et al. 1979. Hatching success and larval mortality in an estuarine teleost, *Menidia menidia* (Linnaeus), exposed to cadmium in constant and fluctuating salinity regimes. Bull. Environ. Contam. Toxicol. 23: 475.

Voyer, R.A., et al. 1982. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to mixtures of cadmium and silver in combination with selected fixed salinities. Aquat. Toxicol. 2: 223.

Vranken, G., R. Vanderhaeghen and C. Heip. 1985. Toxicity of cadmium to free-living marine and brackish water nematodes (*Monhystera microphthalma*, *Monhystera disjuncta*, *Pellioditis marina*). Dis. Aquat. Org. 1: 49-58.

Vuori, K.M. 1993. Influence of water quality and feeding habits on the whole-body metal concentrations in lotic trichopteran larvae. Limnologica. 23(4): 301-308.

Vuori, K.M. 1994. Rapid behavioral and morphological responses of hydropsychid larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure. Environ. Pollut. 84: 291-299.

Vykusova, B. and Z. Svobodova. 1987. Comparison of the sensitivity of male and female guppies (*Poecilia reticulata* Peters) to toxic substances. Bull. Vurh Vodnany. (CZE)(ENG ABS). 23(3): 20-23.

Vymazal, J. 1984. Short-term uptake of heavy metals by periphyton algae. Hydrobiol. 119: 171-179.

Vymazal, J. 1990a. Toxicity and accumulation of lead with respect to algae and cyanobacteria: a review. Acta Hydrochim. Hydrobiol. 18(5): 513-535.

Vymazal, J. 1990b. Uptake of lead, chromium, cadmium and cobalt by *Cladophora glomerata*. Bull. Environ. Contam. Toxicol. 44: 468-472.

Vymazal, J. 1995. Influence of pH on heavy metals uptake by *Cladophora glomerata*. Pol. Arch. Hydrobiol. 42(3): 231-237.

Wall, S.B., J.J. Isley and T.W. La Point. 1996. Fish bioturbation of cadmium-contaminated sediments: factors affecting Cd availability to *Daphnia magna*. Environ. Toxicol. Chem. 15(3): 294-298.

Wallace, W.G. and G.R. Lopez. 1997. Bioavailability of biologically sequestered cadmium and the implications of metal detoxification. Mar. Ecol. Prog. Ser. 147: 149-157.

Walsh, G.E., L.L. McLaughlin, M.J. Yoder, P.H. Moody, E.M. Lores, J. Forester and P.B. Wessinger-Duvall. 1988. *Minutocellus polymorphus*: a new marine diatom for use in algal toxicity tests. Environ. Toxicol. Chem. 7: 925-929.

Walsh, K., R.H. Dunstan, R.N. Murdoch. 1995. Differential bioaccumulation of heavy metals and organopollutants in the soft tissue and shell of the marine gastropod, *Austrocochlea constricta*. Arch. Environ. Contam. Toxicol. 28: 35-39.

Walsh, R.S. and K.A. Hunter. 1992. Influence of phosphorus storage on the uptake of cadmium by the marine alga *Macrocystis pyrifera*. Limnol. Oceanogr. 37(7): 1361-1369.

Wang, J., M. Zhang, J. Xu and Y, Wang. 1995. Reciprocal effect of Cu, Cd, Zn on a kind of marine alga. Water Res. 29(1): 209-214.

Wang, W. 1986. Toxicity tests of aquatic pollutants by using common duckweed. Environ. Pollut. (Series B). 11: 1-14.

Wang, W.X. and N.S. Fisher. 1996. Assimilation of trace elements and carbon by the mussel *Mytilus edulis*: effects of food composition. Limnol. Oceanogr. 41(2): 197-207.

Wang, W.X. and N.S. Fisher. 1998. Accumulation of trace elements in a marine copepod. Limnol. Oceanogr. 43(2): 273-283.

Wang, W.X., N.S. Fisher and S.N. Luoma. 1996. Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*. Mar. Ecol. Prog. Ser. 140: 91-113.

Wani, G.P. 1986. Toxicity of heavy metals to embryonic stages of *Cyprinus carpio* communis Pollut. Res. 5(2): 47-51.

Warnau, M., G. Ledent, A. Temara, V. Alva, M. Jangoux and P. Dubois. 1995a. Allometry of heavy metal bioconcentration in the echinoid *Paracentrotus lividus*. Arch. Environ. Contam. Toxicol. 29: 393-399.

Warnau, M., G. Ledent, A. Temara, M Jangoux and P. Dubois. 1995b. Experimental cadmium contamination of the echinoid *Paracentrotus lividus*: influence of exposure mode and distribution of the metal in the organism. Mar. Ecol. Prog. Ser. 116: 117-124.

Warnau, M., J.L. Teyssie and S.W. Fowler. 1995c. Effect of feeding on cadmium bioaccumulation in the echinoid *Paracentrotus lividus* (Echinodermata). Mar. Ecol. Prog. Ser. 126: 305-309.

Warnau, M., S.W. Fowler and J.L. Teyssie. 1996a. Biokinetics of selected heavy metals and radionuclides in two marine macrophytes: the seagrass *Posidonia oceanica* and the alga *Caulerpa taxifolia*. Mar. Environ. Res. 41(4): 343-362.

Warnau, M., M. Iaccarino, A. De Biase, A. Temara, M. Jangoux, P. Dubois and G. Pagano. 1996b. Spermiotoxicity and embryotoxicity of heavy metals in the echinoid *Paracentrotus lividus*. Environ. Toxicol. Chem. 15(11): 1931-1936.

Warnau, M., J.L. Teyssie and S.W. Fowler. 1997. Cadmium bioconcentration in the echinoid *Paracentrotus lividus*: influence of the cadmium concentration in seawater. Mar. Environ. Res. 43(4): 303-314.

Warnick, S.L. and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. J. Water Pollut. Control Fed. 41: 280.

Warren, L.A., A. Tessier and L. Hare. 1998. Modelling cadmium accumulation by benthic invertebrates *in situ*: the relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations. Limnol. Oceanogr. 43(7): 1442-1454.

Watling, H.R. 1981. Effects of metals on the development of oyster embryos. South African J. Sci. 77: 134.

Watling, H.R. 1982. Comparative study on the effects of zinc, cadmium, and copper on the larval growth of three oyster species. Bull. Environ. Contam. Toxicol. 28: 195.

Watling, H.R. 1983a. Accumulation of seven metals by *Crassostrea gigas*, *Crassostrea margaritacea*, *Perna perna*, and *Choromytilus meridionalis*. Bull. Environ. Contam. Toxicol. 30: 317.

Watling, H.R. 1983b. Comparative study on the effects of metals on the settlement of *Crassostrea gigas*. Bull. Environ. Contam. Toxicol. 31: 344.

Watson, C.F. 1988. Sublethal effects of cadmium exposure on freshwater teleosts. Dissertation. Northeast Louisiana University. pp. 136.

Weber, W.J., Jr. and W. Stumm. 1963. Mechanism of hydrogen ion buffering in natural waters. J. Am. Water Works Assoc. 55: 1553.

Weimin, Y., G.E. Batley and M. Ahsanuullah. 1994. Metal bioavailability to the soldier crab *Mictyris longicarpus*. Sci. Total Environ. 141: 27-44.

Weis, J.S., et al. 1981. Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (*Fundulus heteroclitus*). Rapp. P. V. Reun. Cons. Int. Explor. Mer. 178: 64.

Westerman, A.G. and W.J. Birge. 1978. Accelerated rate of albinism in channel catfish exposed to metals. Prog. Fish-Cult. 40: 143.

Westernhagen, H.V. and V. Dethlefsen. 1975. Combined effects of cadmium and salinity on development and survival of flounder eggs. J. Mar. Biol. Assoc. U.K. 55: 945.

Westernhagen, H.V., et al. 1975. Combined effects of cadmium and salinity on development and survival of garpike eggs. Helgol. Wiss. Meeresunters. 27: 268.

Westernhagen, H.V., et al. 1978. Fate and effects of cadmium in an experimental marine ecosystem. Helgol. Wiss. Meeresunters. 31: 471.

Westernhagen, H.V., et al. 1979. Combined effects of cadmium, copper and lead on developing herring eggs and larvae. Helgol. Wiss. Meeresunters. 32: 257.

White, D.H. and M.T. Finley. 1978a. Effects of dietary cadmium in mallard ducks. *In:* D.D. Hemphill (ed.), Trace Substances in Environmental Health-XII. University of Missouri, Columbia, Missouri. p. 220.

White, D.H. and M.T. Finley. 1978b. Uptake and retention of dietary cadmium in mallard ducks. Environ. Res. 17: 53.

White, D.H., et al. 1978. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. Toxicol. Environ. Health 4: 551.

White, S.L. and P.S. Rainbow. 1982. Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*. Mar. Ecol. Prog. Ser. 8: 95.

White, S.L. and P.S. Rainbow. 1986. Accumulation of cadmium by *Palaemon elegans* (Crustacea: Decapoda). Mar. Ecol. Prog. Ser. 32: 17-25.

Wicklum, D. and R.W. Davies. 1996. The effects of chronic cadmium stress on energy acquisition and allocation in a freshwater benthic invertebrate predator. Aquat. Toxicol. 35: 237-252.

Wicklum, D., D.E.C. Smith and R.W. Davies. 1997. Mortality, preference, avoidance, and activity of a predatory leech exposed to cadmium. Arch. Environ. Contam. Toxicol. 32: 178-183.

Wicklund, A. and P. Runn. 1988. Calcium effects on cadmium uptake, redistribution, and elimination in minnows, *Phoxinus phoxinus*, acclimated to different calcium concentrations. Aquat. Toxicol. 13: 109-122.

Wicklund, A., P. Runn and L. Norrgren. 1988. Cadmium and zinc interactions in fish: effects of zinc on the uptake, organ distribution, and elimination of ^{109}Cd in the zebrafish, *Brachydanio rerio*. Arch. Environ. Contam. Toxicol. 17: 345-354.

Wier, C.F. and W.M. Walter. 1976. Toxicity of cadmium in the freshwater snail, *Physa gyrina* Say. J. Environ. Qual. 5: 359.

Wikfors, G.H. and R. Ukeles. 1982. Growth and adaptation of estuarine unicellular algae in media with excess copper, cadmium or zinc, and effects of metal-contaminated algal food on *Crassostrea virginica* larvae. Mar. Ecol. Prog. Ser. 7: 191.

Wilczok, A., U. Mazurek, D. Tyrawska and B. Sosak-Swiderska. 1994. Effect of cadmium on the cell division of *Chlorella vulgaris* Beij. 1890, strain A-8. Pol. Arch. Hydrobiol. 41(1): 123-131.

Wildgust, M.A. and M.B. Jones. 1998. Salinity change and the toxicity of the free cadmium ion [$Cd^{2+}_{(aq)}$] to *Neomysis integer* (Crustacea: Mysidacea). Aquat. Toxicol. 41: 187-192.

Williams, C.J., D. Aderhold and R.G.J. Edyvean. 1998. Comparison between biosorbents for the removal of metal ions from aqueous solutions. Water Res. 32: 216-224

Williams, D.R. and J.P. Giesy, Jr. 1978. Relative importance of food and water sources to cadmium uptake by *Gambusia affinis* (Poeciliidae). Environ. Res. 16: 326.

Williams, K.A., D.W.J. Green and D. Pascoe. 1985. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates ; 1: Cadmium. Arch. Hydrobiol. 102(4): 461-471.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1986. The acute toxicity of cadmium to different larval stages of *Chironomus riparius* (Diptera: Chironomidae) and its ecological significance for pollution regulation. Oecologia. 70(3): 362-366.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1987. Effect of cadmium on oviposition and egg viability in *Chironomus riparius* (Diptera: Chironomidae). Bull. Environ. Contam. Toxicol. 38: 86-90.

Williams, P.L and D.B. Dusenbery. 1990. Aquatic toxicity testing using the nematode, *Caenorhabditis elegans*. Environ. Toxicol. Chem. 9:1285-1290.

Windom, H.L., et al. 1982. Metal accumulation by the polychaete *Capitella capitata*: influences of metal content and nutritional quality of detritus. Can. J. Fish. Aquat. Sci. 39: 191.

Winner, R.W. 1984. The toxicity and biaccumulation of cadmium and copper as affected by humic acid. Aquat. Toxicol. 5: 267.

Winner, R.W. 1986. Interactive effects of water hardness and humic acid on the chronic toxicity of cadmium to *Daphnia pulex*. Aquat. Toxicol. 8: 281-293.

Winner. R.W. 1988. Evaluation of the relative sensitivities of 7-d *Daphnia magna* and *Ceriodaphnia dubia* toxicity tests for cadmium and sodium pentachlorophenate. Environ. Toxicol. Chem. 7: 153-159.

Winner, R.W. and J.D. Gauss. 1986. Relationship between chronic toxicity and bioaccumulation of copper, cadmium and zinc as affected by water hardness and humic acid. Aquat. Toxicol. 8: 149-161.

Winner, R.W. and T.C. Whitford. 1987. The interactive effects of a cadmium stress, a selenium deficiency and water temperature on the survival and reproduction of *Daphnia magna* Straus. Aquat. Toxicol. 10: 217-224.

Winter, S. 1996. Cadmium uptake kinetics by freshwater mollusc soft body under hard and soft water conditions. Chemosphere. 32(10): 1937-1948.

Witeska, M., B. Jezierska and J. Chaber. 1995. The influence of cadmium on common carp embryos and larvae. Aquaculture. 129: 129-132.

Witzel, B. 1998. Uptake, storage and loss of cadmium and lead in the woodlouse *Porcellio scaber* (Crustacea, Isopoda). Water, Air, Soil Pollut. 108: 51-68.

Wong, C.K. 1989. Effects of cadmium on the feeding behavior of the freshwater cladoceran *Moina macrocopa*. Chemosphere. 18(7/8): 1681-1687.

Wong, C.K. and P.K. Wong. 1990. Life table evaluation of the effects of cadmium exposure on the freshwater cladoceran, *Moina macrocopa*. Bull. Environ. Contam. Toxicol. 44: 135-141.

Wong, P.T.S. 1987. Toxicity of cadmium to freshwater microorganisms, phytoplankton, and invertebrates. Adv. Environ. Sci. Tech. 19: 117-138.

Wong, P.T.S., et al. 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11: 367.

Woodall, C., N. Maclean and F. Crossley. 1988. Responses of trout fry (*Salmo gairdneri*) and *Xenopus laevis* tadpoles to cadmium and zinc. Comp. Biochem. Physiol. 89C(1): 93-99.

Woodling, J.D. 1993. Survival and mortality of brown trout (*Salmo trutta*) exposed to *in situ* acute toxic concentrations of cadmium and zinc. Dissertation. University of Colorado at Boulder. pp. 130.

Woodward, D.F., A.M. Farag, H.L. Bergman, A.J. DeLonay, E.E. Little, C.E. Smith and F.T. Barrow. 1995. Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: effects on age-0 brown trout and rainbow trout. Can. J. Fish. Aquat. Sci. 52: 1994-2004.

Woodworth, J. and D. Pascoe. 1982. Cadmium toxicity to rainbow trout, *Salmo gairdneri* Richardson: a study of eggs and alevins. J. Fish Biol. 21: 47.

Woodworth, J. and D. Pascoe. 1983. Cadmium uptake and distribution in sticklebacks related to the concentration and method of exposure. Ecotoxicol. Environ. Safety. 7: 525-530.

Wren, M.J. and D. McCarroll. 1990. A simple and sensitive bioassay for the detection of toxic materials using a unicellular green alga. Environ. Pollut. 64: 87-91.

Wright, D.A. 1977. The effect of salinity on cadmium uptake by the tissues of the shore crab, *Carcinus maenas*. Exp. Biol. 67: 137.

Wright, D.A. 1988. Dose-related toxicity of copper and cadmium in striped bass larvae from the Chespeake Bay: field considerations. Water Sci. Tech. 20(6/7): 39-48.

Wright, D.A. and J.W. Frain. 1981. Cadmium toxicity in *Marinogammarus obtusatus*: effect of external calcium. Environ. Res. 24: 338.

Wright, D.A. and P.M. Welbourn. 1994. Cadmium in the aquatic environment: a review of ecological, physiological, and toxicological effects on biota. Environ. Rev. 2: 187-214.

Wright, D.A., M.J. Meteyer and F.D. Martin. 1985. Effect of calcium on cadmium uptake and toxicity in larvae and juveniles of striped bass (*Morone saxatilis*). Bull. Environ. Contam. Toxicol. 34(2): 196-204.

Wu, R.S.S., P.K.S. Lam and B. Zhou. 1997. A settlement inhibition assay with cyprid larvae of the barnacle *Balanus amphitrite*. Chemosphere. 35(9): 1867-1874.

Wundram, M., D. Selmar and M. Bahadir. 1996. The *Chlamydomonas* test: a new phytotoxicity test based on the inhibition of algal photosynthesis enables the assessment of hazardous leachates from waste disposals in salt mines. Chemosphere. 32(8): 1623-1632.

Xiaorong, W., J. Mei, S. Hao and X. Ouyong. 1997. Effects of chelation on the bioconcentration of cadmium and copper by carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 59: 120-124.

Xue, H. and L. Sigg. 1998. Cadmium speciation and complexation by natural organic ligands in freshwater. Analytica Chemica Acta. 363: 249-259.

Yager, C.M. and H.W. Harry. 1964. The uptake of radioactive zinc, cadmium and copper by the freshwater snail, *Taphius glabratus*. Malacologia 1: 339.

Yamamoto, Y. and M. Inoue. 1985. Lethal tolerance of acute cadmium toxicity in rainbow trout previously exposed to cadmium. Bull. Jpn. Soc. Sci. Fish. 51(10): 1733-1735.

Zanders, I.P. and W.E. Rojas. 1996. Salinity effects on cadmium accumulation in various tissues of the tropical fiddler crab *Uca rapax*. Environ. Pollut. 94(3): 293-299.

Zaroogian, G.E. 1979. Studies on the depuration of cadmium and copper by the American oyster *Crassostrea virginica*. Bull. Environ. Contam. Toxicol. 23: 117.

Zaroogian, G.E. 1980. *Crassostrea virginica* as an indicator of cadmium pollution. Mar. Biol. (Berlin). 58(4): 275-284.

Zaroogian, G.E. and S. Cheer. 1976. Cadmium accumulation by the American oyster, *Crassostrea virginica*. Nature. 261: 408.

Zaroogian, G.E. and G. Morrison. 1981. Effect of cadmium body burdens in adult *Crassostrea virginica* on fecundity and viability of larvae. Bull. Environ. Contam. Toxicol. 27: 344.

Zauke, G.P., R. Von Lemm, H.G. Meurs and W. Butte. 1995. Validation of estuarine gammarid collectives (Amphipoda: Crustacea) as biomonitors for cadmium in semi-controlled toxicokinetic flow-through experiments. Environ. Pollut. 90(2): 209-219.

Zhang, M., J. Wang and J. Bao. 1992. Study on the relationship between speciation of heavy metals and their ecotoxicity. Chin. J. Oceanol. Limnol. 10(3): 215-222.

Zia, S. and D.G. McDonald. 1994. Role of the gills and gill chloride cells in metal uptake in the freshwater-adapted rainbow trout, *Oncorhynchus mykiss*. Can. J. Fish. Aquat. Sci. 51: 2482-2492.

Zou, E. and S. Bu. 1994. Acute toxicity of copper, cadmium, and zinc to the water flea, *Moina irrasa* (Cladocera). Bull. Environ. Contam. Toxicol. 52: 742-748.

Zuiderveen, J.A. and W.J. Birge. 1997. The relationship between chronic values in toxicity tests with *Ceriodaphnia dubia*. *In:* Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (sixth volume), ASTM STP 1317, F.J. Dwyer, T.R. Doane and M.L. Hinman (eds), American Society for Testing and Materials. pp. 551-556.