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# 2001 Update of Ambient Water Quality Criteria for Cadmium

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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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## 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

[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.

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 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. capitata*, 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 ± 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).

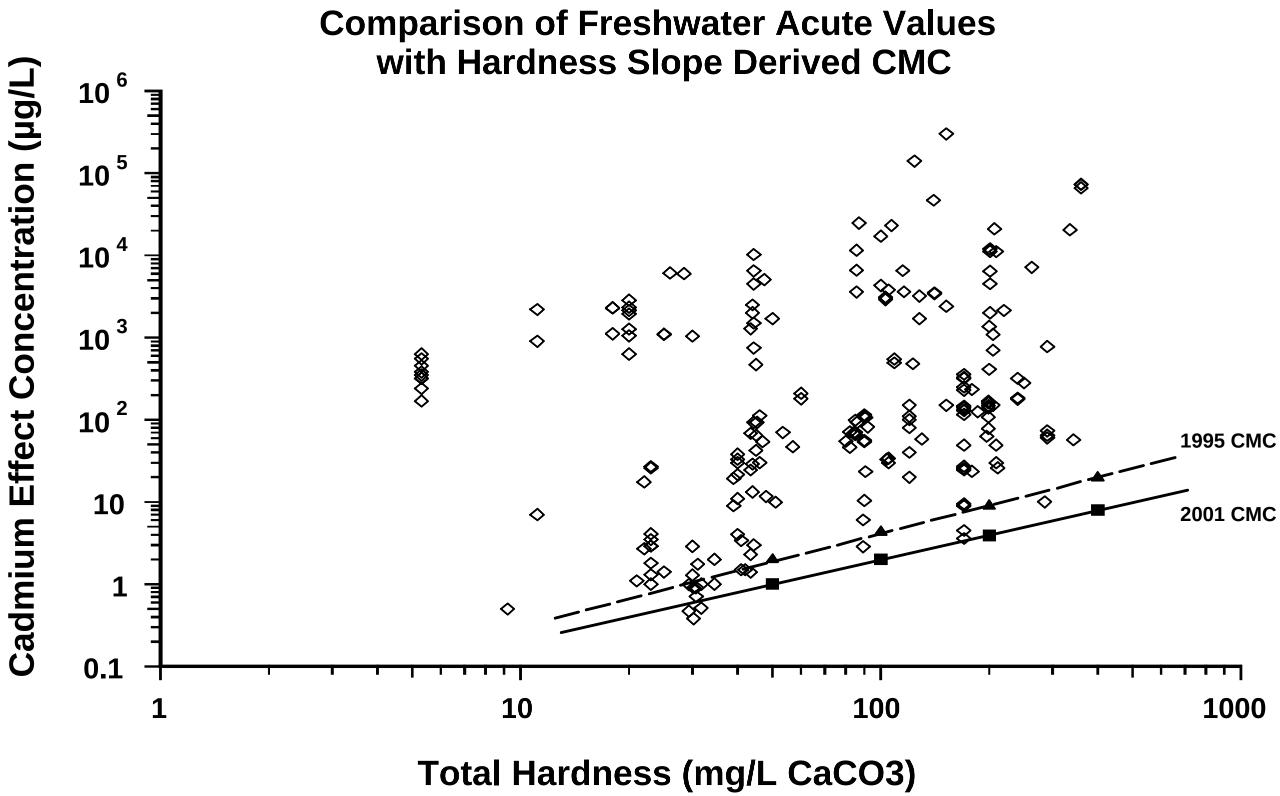


Figure 1. Comparison of All Table 1 Freshwater Acute Toxicity Test EC50s and LC50s with the Hardness Slope Derived CMC. (2001 CMC: solid line; 1995 CMC: dashed line)

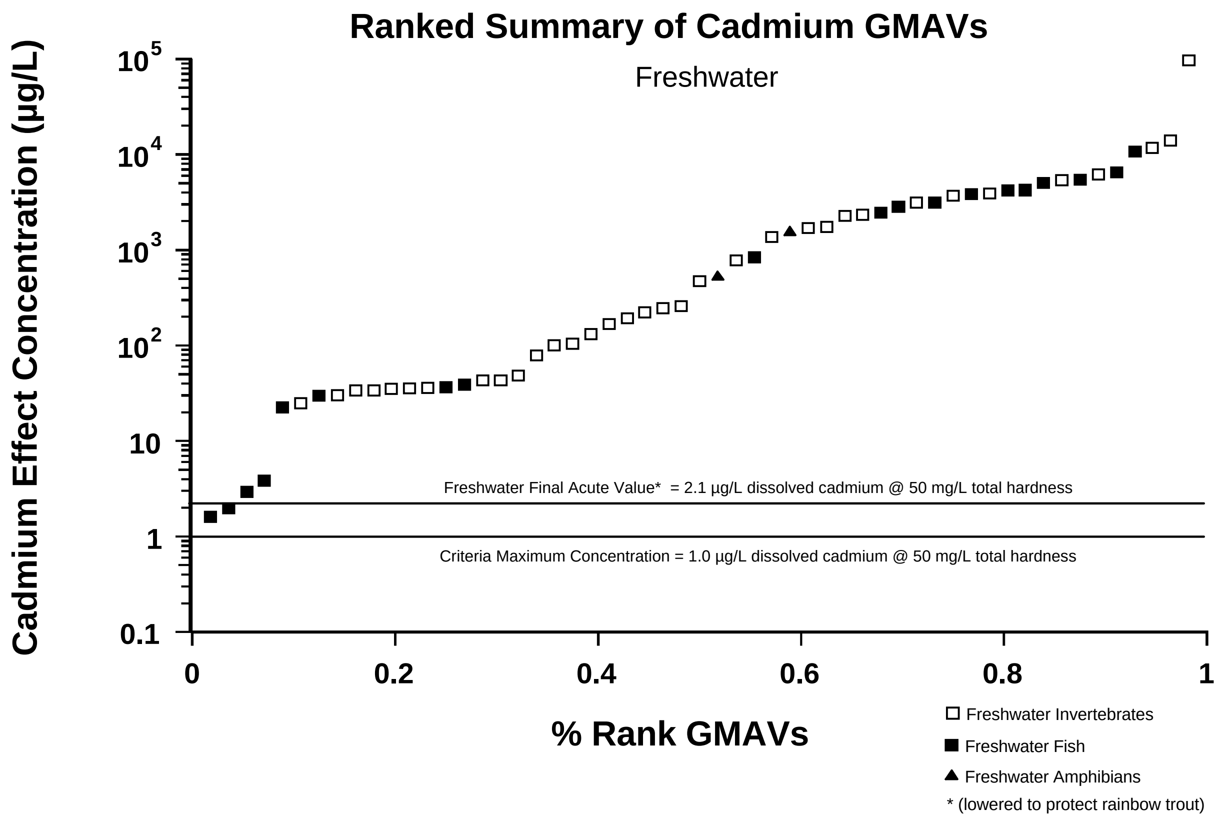


Figure 2. Ranked Summary of Cadmium GMAVs (Freshwater).

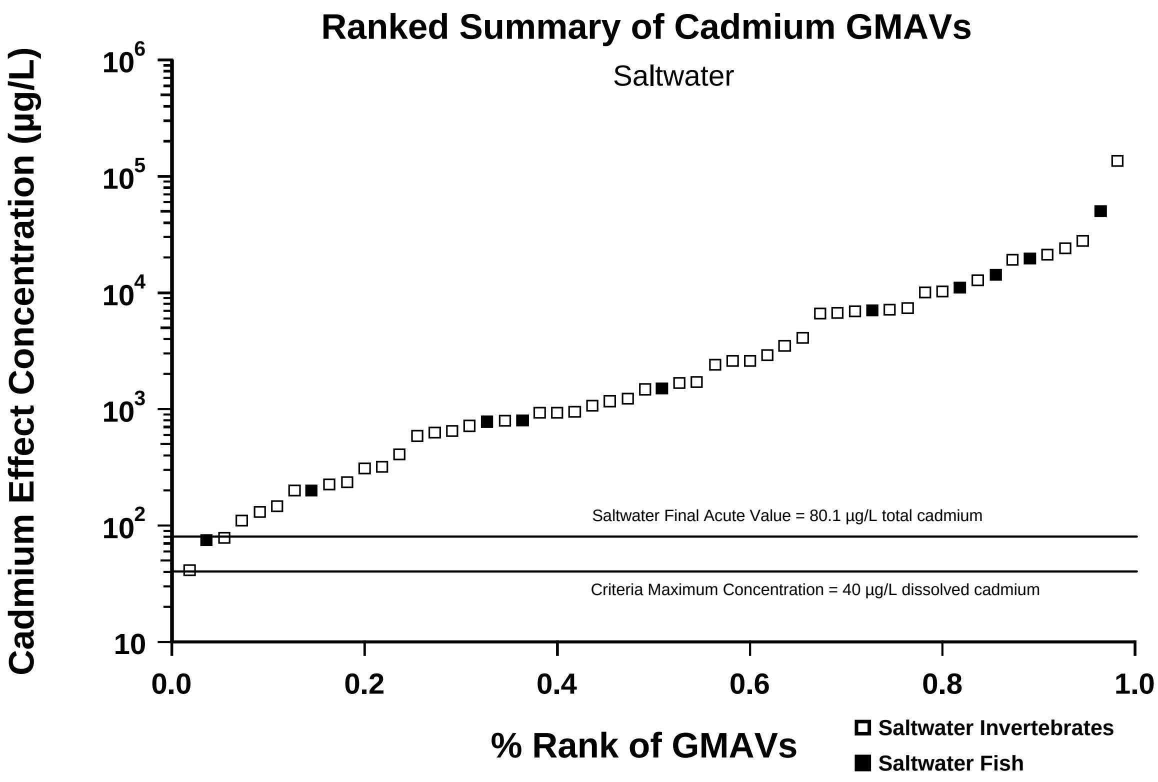


Figure 3. Ranked Summary of Cadmium GMAVs (Saltwater).

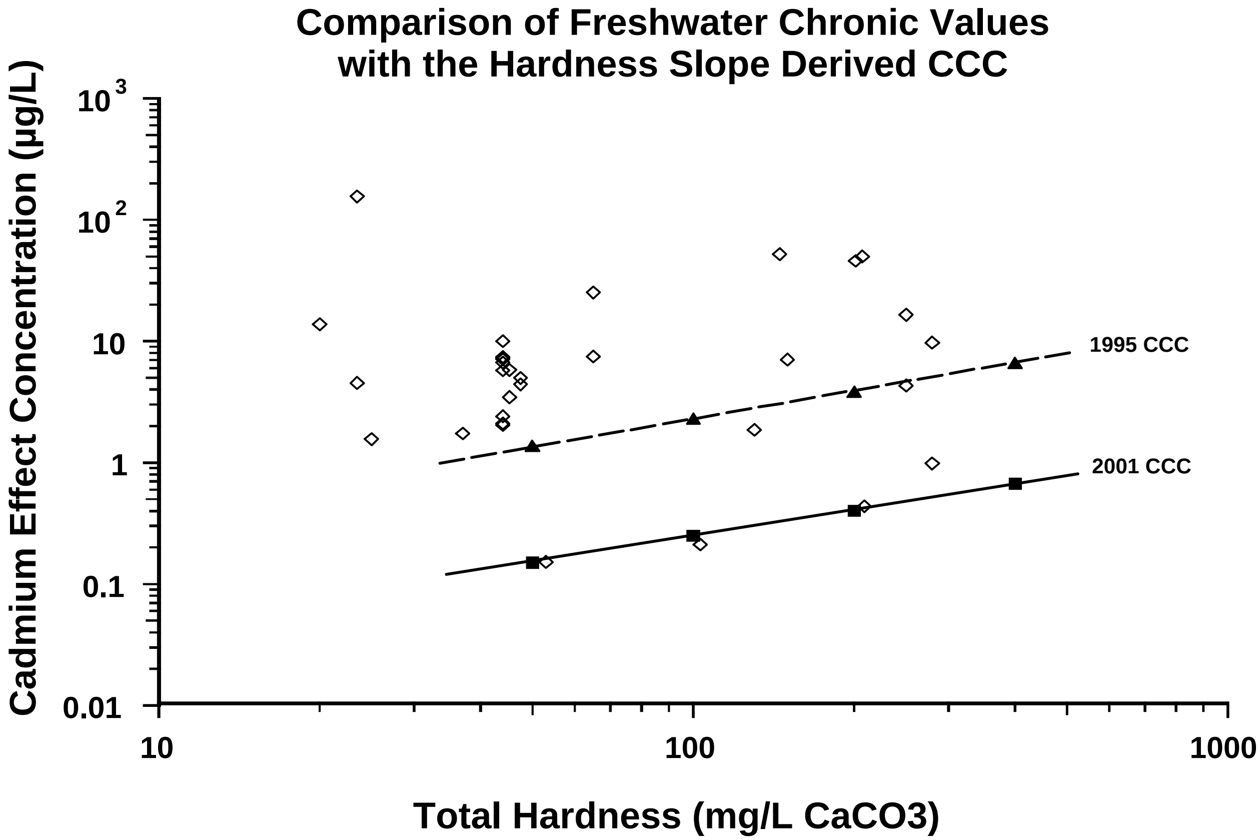


Figure 4. Comparison of All Table 2 Freshwater Chronic Values with the Hardness Slope Derived CCC.
(2001 CCC: solid line; 1995 CCC: dashed line)

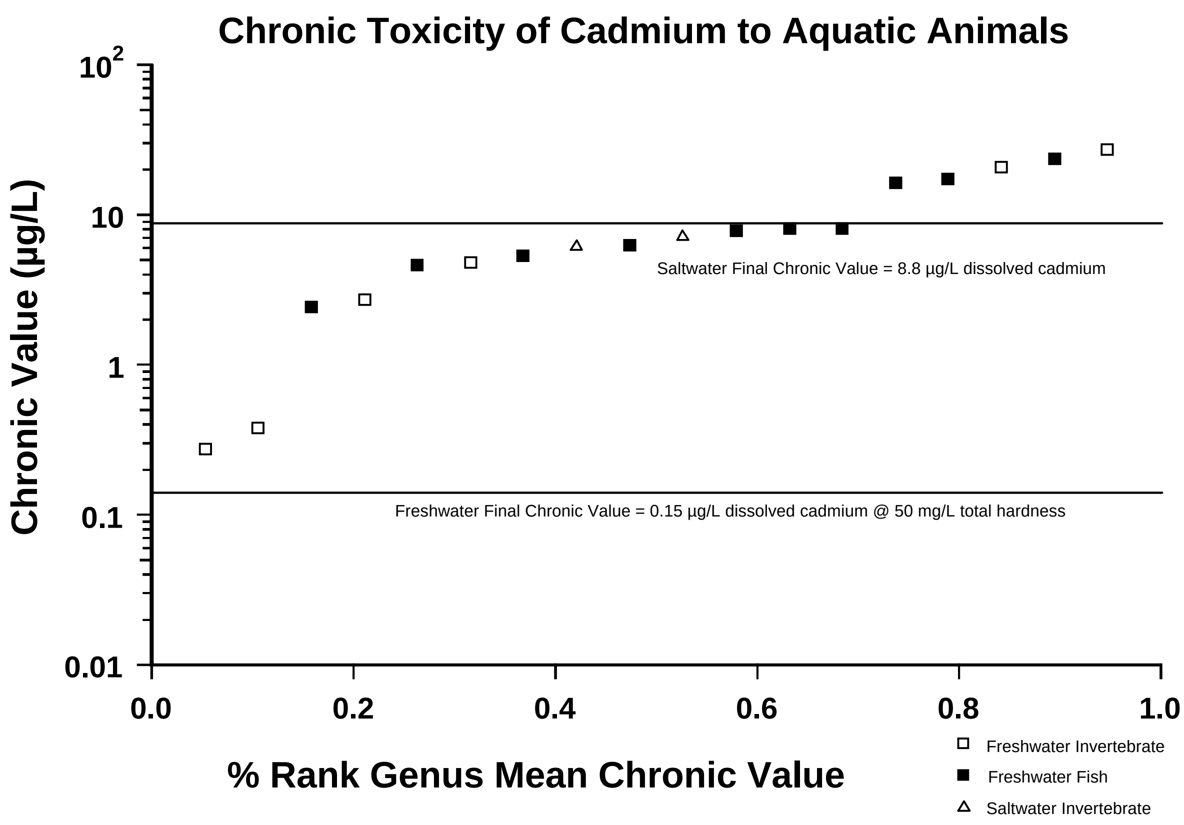


Figure 5. Chronic Toxicity of Cadmium to Aquatic Animals.

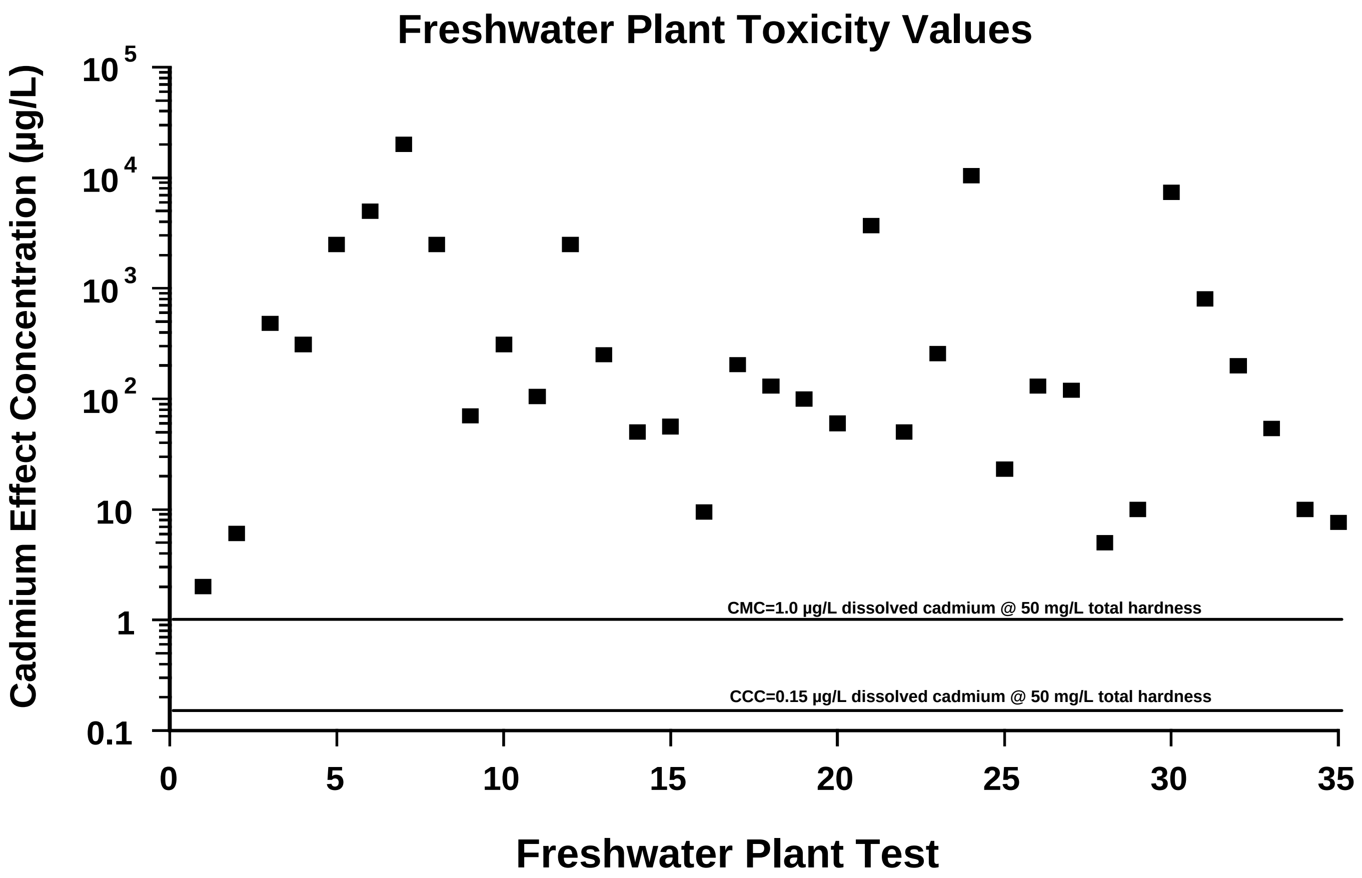


Figure 6. Comparison of Freshwater Plant Toxicity Values (Table 4) and Freshwater CMC and CCC Values.

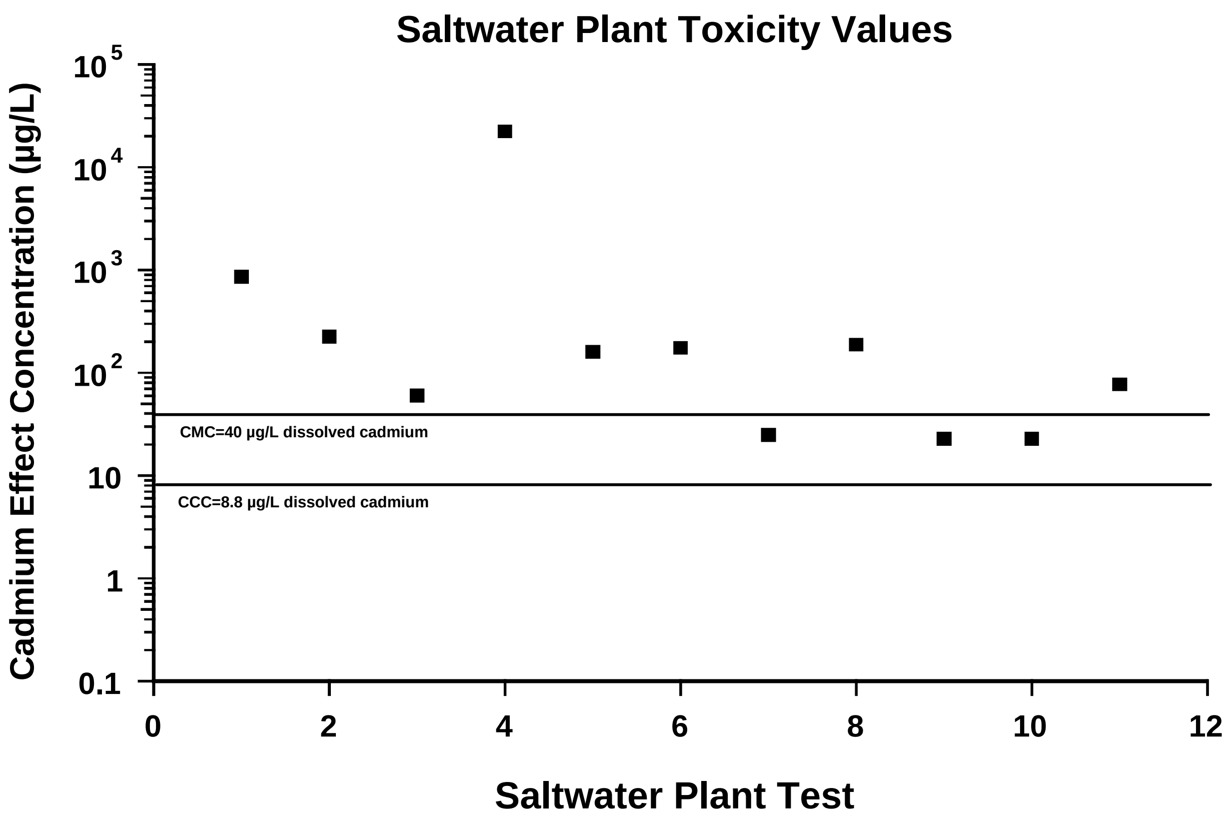


Figure 7. Comparison of Saltwater Plant Toxicity Values (Table 4) and Saltwater CMC and CCC Values.

**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, | S, M | Cadmium | 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 | - | **3,721** | 3,721 | Chapman et al. 1982 |
| Leech, *Glossiponia complanta* | R, M, T | Cadmium chloride | 122.8 | 480 | - | **192.5** | 192.5 | Brown and Pascoe 1988 |
| Snail, *Aplexa hypnorum* | F, M | Cadmium chloride | 45.3 | 93 | - | **102.8** | - | Holcombe et al. 1984 |
| Snail (adult), *Aplexa hypnorum* | F, M, T | Cadmium chloride | 44.4 | 93 | - | **104.9** | 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 | - | **100.2** | 100.2 | Wier and Walter 1976 |
| Mussel (juvenil), *Actinonaia pectorosa* | S,M,T | - | 82 | 46.4 | - | **28.06** | - | Keller Unpublished |
| Mussel (juvenile), *Actinonaia pectorosa* | S,M,T | - | 84 | 69 | - | **40.72** | 33.80 | Keller Unpublished |
| Mussel (juvenile), *Lampsilis straminea claibornensis* | S,M,T | - | 40 | 38 | - | **47.68** | 47.68 | Keller Unpublished |
| Mussel, *Lampsilis teres* | S,M,T | - | 40 | 11 | - | **13.80** | - | Keller Unpublished |
| Mussel (juvenile), *Lampsilis teres* | S,M,T | - | 40 | 33 | - | **41.40** | 23.90 | Keller Unpublished |
| Mussel, *Utterbackia imbecilis* | S, M, T | Cadmium chloride | 90 | 114.7 | - | **63.10** | - | Keller Unpublished |
| Mussel, *Utterbackia imbecilis* | S, M, T | Cadmium chloride | 90 | 111.8 | - | **61.51** | - | Keller Unpublished |
| Mussel (juvenile), *Utterbackia imbecilis* | S,M,T | Cadmium chloride | 92 | 81.9 | - | **44.06** | - | Keller Unpublished |
| Mussel (juvenile), | S,M,T | Cadmium | 86 | 93.0 | - | **53.59** | - | Keller Unpublished |

**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 | 39 | 9 | - | **11.59** | - | Keller and Zam 1991 |
| 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), | S, U | Cadmium | - | 35.45 | - | - | - | Canton and Adema 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 | | | | |
| 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 |
| 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), | S, M, T | Cadmium | 170 | 49.1 | - | 14.15[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 (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 |
| 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 | - | **54.52** | - | Crisinel et al. 1994 |
| Cladoceran (<24 hr), *Daphnia magna* | S, U | Cadmium chloride | 170 (160-180) | 9.5 | - | **2.738** | - | Guilhermino et al. 1996 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 46.1 | 112 (clone S-1) | 104 | **121.6** | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 90.7 | 106 (clone S-1) | 91.4 | **57.86** | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 179 | 233 (clone S-1) | 179 | **63.72** | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 46.1 | 30.1 (clone A) | 27.8 | **32.69** | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 90.7 | 23.4 (clone A) | 20.2 | **12.77** | - | Barata et al. 1998 |
| Cladoceran, | S, M, T | Cadmium | 179 | 23.6 | 18.1 | **6.454** | - | Barata et al. 1998 |

**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 | 51 | 9.9 | - | **9.703** | - | Chapman et al. Manuscript |
| Cladoceran (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 104 | 33 | - | **15.67** | - | Chapman et al. Manuscript |
| Cladoceran (<24 hr), *Daphnia magna* | S, M, T | Cadmium Chloride | 105 | 34 | - | **15.99** | - | Chapman et al. Manuscript |
| Cladoceran (<24 hr), *Daphnia magna* | S, M, T | Cadmium Chloride | 197 | 63 | - | **15.63** | - | Chapman et al. Manuscript |
| 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, | S, U | Cadmium | 82 | 71.25 | - | **43.09** | 43.09 | Hatakeyama and Yasuno |

**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, *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 |
| 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 (4[th] instar), | R, M, T | Cadmium | 124 | 140,000 | - | 55,607 | - | Pascoe et al. 1990 |

**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 | | | | |
| 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 |
| 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 | - | **6.221** | 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* | F, M | Cadmium chloride | 23 | 1.8 | - | **3.964** | - | Chapman 1975, 1978 |
| Chinook salmon | F, M | Cadmium | 23 | 3.5 | - | **7.707** | - | Chapman 1975, 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 | | | | |
| Chinook salmon (smolt), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 23 | >2.9 | - | **>6.386** | - | Chapman 1975, 1978 |
| Chinook salmon (juvenile), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 25 | 1.41 | - | **2.853** | - | Chapman 1982 |
| Chinook salmon (juvenile), *Oncorhynchus tshawytscha* | F, M | Cadmium sulfate | 21 (20-22) | 1.1 | - | **2.657** | 4.305 | Finlayson and Verrue 1982 |
| 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 | - | **2.863** | - | Chapman 1975, 1978 |
| Rainbow trout (parr), *Oncorhynchus mykiss* | F, M | Cadmium chloride | 23 | 1.0 | - | **2.202** | - | Chapman 1978 |
| Rainbow trout (smolt), *Oncorhynchus mykiss* | F, M | Cadmium chloride | 23 | 4.1<br>>2.9 | - | **9.029**<br>**>6.386** | -<br>- | Chapman 1975 |
| Rainbow trout (2 mo), | F, M | Cadmium | - | 6.6 | - | - | - | Hale 1977 |

**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* | F, M | Cadmium sulfate | 31 | 1.75 | - | **2.845** | - | Davies 1976 |
| Rainbow trout (8.8 g), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 44.4 | 3 | - | **3.385** | - | Phipps and Holcombe 1985 |
| Rainbow trout (fry), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 9.2 | <0.5 | - | **<2.795** | - | Cusimano et al. 1986 |
| Rainbow trout (263 mg), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 30.7 | 0.71 (pH=7.5 @ 8°C) | - | **1.166** | - | Stratus Consulting 1999 |
| Rainbow trout (659 mg), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 29.3 | 0.47 (pH=7.5 @ 8°C) | - | **0.8092** | - | Stratus Consulting 1999 |
| 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), | F, M, T | Cadmium | 29.3 | 0.99 | - | **1.705** | - | 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 | | | | |
| 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 |
| 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 | S, M, T | Cadmium | 85.5 | 6,620 | - | **3,837** | 3,837 | Carrier and Beitinger 1988a |

**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, 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 |
| 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 | S, M | Cadmium | 103 | 3,060[d] | - | 1,468[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 (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 |
| 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 | - | **<u>174.5</u>** | - | Rifici et al. 1996 |
| Fathead minnow (1-2 d), *Pimephales promelas* | S, U | Cadmium nitrate | 60 | 180 | - | **<u>149.5</u>** | - | Rifici et al. 1996 |
| Fathead minnow (<24 hr), *Pimephales promelas* | S, M, T | Cadmium nitrate | 290 (280-300) | 73 (pH=6-6.5)<br>60 (pH=7-7.5)<br>65 (pH=8-8.8) | -<br>-<br>- | **<u>12.22</u>**<br>**<u>10.05</u>**<br>**<u>10.88</u>** | -<br>-<br>- | 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), | F, M, T | Cadmium chloride | 44.4 | 1,500[d] | - | 1,693[d] | - | Phipps and Holcombe 1985 |
| Fathead minnow | F, M, T | Cadmium | 44 | 13.2 | - | **<u>15.03</u>** | 29.21 | Spehar and Fiandt 1986 |

**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 | | | | |
| 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 |
| 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, | F, M | Cadmium | 11.1 | 900 | - | **4,157** | - | Giesy et al. 1977 |

**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 | | | | |
| 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 |
| 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), | S, M, T | Cadmium sulfate | 85.5 | 11,520 | - | 6,677 | - | Carrier and Beitinger 1988b |
| Green sunfish, | F, M | Cadmium | 335 | 20,500 | - | **2,965** | 2,965 | Jude 1973 |

**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, *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 |
| 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 | - | **12,000** | - | - | Reish et al. 1976 |
| Polychaete worm (juvenile), *Neanthes arenaceodentata* | S, U | Cadmium chloride | - | **12,500** | - | - | Reish et al. 1976 |
| Polychaete worm, *Neanthes arenaceodentata* | S, U | Cadmium chloride | - | **14,100** | - | 12,836 | Reish and LeMay 1991 |
| Polychaete worm, *Nereis grubei* | S, U | Cadmium chloride | - | **4,700** | - | 4,700 | Reish and LeMay 1991 |
| Sand worm, *Nereis virens* | S, U | Cadmium chloride | - | **11,000** | - | - | Eisler 1971 |
| Sand worm, *Nereis virens* | S, U | Cadmium chloride | - | **9,300** | - | 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 | - | **200** | - | 200 | Reish et al. 1976 |
| Polychaete worm, *Pectinaria californiensis* | S, U | Cadmium chloride | - | **2,600** | - | 2,600 | Reish and LeMay 1991 |
| Oligochaete worm, *Limnodriloides verrucosus* | R, U | Cadmium sulfate | - | **10,000** | - | 10,000 | Chapman et al. 1982 |
| Oligochaete worm, *Monopylephorus cuticulatus* | R, U | Cadmium sulfate | - | **135,000** | - | 135,000 | Chapman et al. 1982 |
| Oligochaete worm, *Tubificoides gabriellae* | R, U | Cadmium sulfate | - | **24,000** | - | 24,000 | Chapman et al. 1982 |
| Oyster drill, *Urosalpinx cinerea* | S, U | Cadmium chloride | - | **6,600** | - | 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[c] | - | - | Eisler 1971 |
| Blue mussel, *Mytilus edulis* | S, M | Cadmium chloride | - | 1,620[c] | - | - | Ahsanullah 1976 |
| Blue mussel, *Mytilus edulis* | F, M | Cadmium chloride | - | 3,600[c] | - | - | Ahsanullah 1976 |
| Blue mussel, *Mytilus edulis* | F, M | Cadmium chloride | - | 4,300[c] | - | - | 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, | S, U | Cadmium | - | **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[c] | - | - | 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** (18NC) | - | - | Toudal and Riisgard 1987 |
| Copepod (adult), *Acartia tonsa* | S, U | Cadmium chloride | 20 | **151** (13NC) | - | - | Toudal and Riisgard 1987 |
| Copepod (adult), *Acartia tonsa* | S, U | Cadmium chloride | 20 | **29** (21NC) | - | 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 (20NC)<br><11.1 (30NC) | -<br>- | -<br>- | Voyer and Modica 1990 |
| Mysid (<24 hr), *Americamysis bahia* | S, M, T | - | 30 | 82.0 (20NC)<br>32.8 (25NC)<br><11.1 (30NC) | -<br>-<br>- | -<br>-<br>- | Voyer and Modica 1990 |
| Mysid, *Americamysis bahia* | F, M | Cadmium chloride | 10-17 | **15.5** | - | - | Nimmo et al. 1977a |
| Mysid, *Americamysis bahia* | F, M | Cadmium chloride | 30 | **110** | - | 41.29 | Gentile et al. 1982; Lussier et al. 1985 |
| Mysid, *Mysidopsis bigelowi* | F, M | Cadmium chloride | 30 | **110** | - | 110 | Gentile et al. 1982 |
| Iosopd, *Jaeropsis* sp. | S, U | Cadmium chloride | 35 | **410.0** | - | 410.0 | Hong and Reish 1987 |
| Isopod, *Limnoria tripunctata* | S, U | Cadmium chloride | 35 | **7,120** | - | 7,120 | Hong and Reish 1987 |
| Amphipod (adult), *Ampelisca abdita* | F, M | Cadmium chloride | - | **2,900** | - | 2,900 | Scott et al. Manuscript |
| Amphipod (adult), *Marinogammarus obtusatus* | S, M | Cadmium chloride | - | 13,000[c] | - | - | Wright and Frain 1981 |
| Amphipod (young), *Marinogammarus obtusatus* | S, M | Cadmium chloride | - | **3,500** | - | 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 (4NC)<br>20 (10NC)<br>20 (15NC) | 49,400[d]<br>17,500[d]<br>**6,700** | -<br>-<br>- | -<br>-<br>6,700 | Gossiaux et al. 1992 |
| 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)<br>**36,100** (held 17 d before testing)<br>**14,500** (held 121 d before testing) | -<br>-<br>- | -<br>-<br>27,992 | Meador 1993 |
| 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[c] | - | - | Nimmo et al. 1977b |
| Pink shrimp (2[nd] 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 |

**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 | 20 | **46,600** | - | - | O'Hara 1973a |
| 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), | S, U | Cadmium | 20 | 92,000 | - | - | 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 | 20 | 78,000 | - | - | Voyer 1975 |
| Mummichog (juvenile), *Fundulus heteroclitus* | S, U | Cadmium chloride | 10 | 73,000 | - | - | Voyer 1975 |
| 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[c] | - | - | Park et al. 1994 |
| Rivulus (120 d adult), *Rivulus marmoratus* | S, M, T | Cadmium chloride | 10 | 32,200[c] | - | - | Park et al. 1994 |
| Rivulus (11-18 mm), *Rivulus marmoratus* | F, M, T | Cadmium sulfate | 14 | 23,700[c] | - | - | Lin and Dunson 1993 |
| Rivulus (11-18 mm), *Rivulus marmoratus* | F, M, T | Cadmium sulfate | 14 | 18,500[c] | - | - | 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[c] | - | - | Cardin 1982 |
| Atlantic silverside (juvenile), *Menidia menidia* | S, U | Cadmium chloride | - | 28,532[c] | - | - | Cardin 1982 |
| Atlantic silverside (juvenile), | S, U | Cadmium | - | 13,652[c] | - | - | 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 | | | |
| 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 |
| 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 µg/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 (5NC) | - | 155.9[c] | - | 272.8[d] | - | Rombough and Garside 1982 |
| | | | | 2.5-8.2 (9.6NC) | - | 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**

Freshwater Species

| Species | Reference | Hardness (mg/L as $CaCO_3$) | Acute Value (µg/L) | Chronic Value (µg/L) | Ratio | Species Mean Acute-Chronic Ratio |
|---|---|---|---|---|---|---|
| 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

| Species | Reference | Hardness (mg/L as $CaCO_3$) | Acute Value (µg/L) | Chronic Value (µg/L) | Ratio | Species Mean Acute-Chronic Ratio |
|---|---|---|---|---|---|---|
| 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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 µg/L)[b] | Species | Species Mean Acute Value (Total µg/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 (µg/L) | Species | Species Mean Chronic Value (µg/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)

1n (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 µg/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<br>7 days<br>10 days | EC50 (cell density)<br>EC50 (cell density)<br>EC50 (cell density) | 203<br>130<br>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 |

**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, *Selenastrum capricornutum* | S, U | Cadmium chloride | 171 | 4 days | EC50 growth | 130 | Versteeg 1990 |
| 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(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 71[b]<br>74[b]<br>109[b] | Tessier et al. 1994a |
| | Soft tissue (2 yrs old) | Cadmium chloride | - | 100(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 28[b]<br>42[b]<br>60[b] | |
| | Soft tissue (3 yrs old) | Cadmium chloride | - | 100(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 27[b]<br>42[b]<br>26[b] | |
| Snail, *Viviparus georgianus* | Soft tissue (1 yr old) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 6,910[b]<br>2,238[b] | Tessier et al. 1994b |
| | Soft tissue (2 yrs old) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 1,758[b]<br>758[b] | |
| | Soft tissue (3 yrs old) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 1,258[b]<br>617[b] | |

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

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in Water (µg/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| | | | FRESHWATER SPECIES | | | | |
| Mussel, *Elliptio complanata* | Soft tissue (0-74 mm length) | Cadmium chloride | - | 100(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 15[b]<br>16[b]<br>28[b] | Tessier et al. 1994a |
| | Soft tissue (74-86 mm length) | Cadmium chloride | - | 100(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 16[b]<br>16[b]<br>14[b] | |
| | Soft tissue (86-100 mm length) | Cadmium chloride | - | 100(10NC)<br>100(15NC)<br>100(25NC) | 20<br>20<br>20 | 8[b]<br>7[b]<br>8[b] | |
| Mussel, *Elliptio complanata* | Soft tissue (0-74 mm length) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 1,256[b]<br>918[b] | Tessier et al. 1994b |
| | Soft tissue (74-86 mm) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 945[b]<br>613[b] | |
| | Soft tissue (86-100 mm) | Cadmium chloride | - | 10<br>50 | 60<br>60 | 574[b]<br>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 (µg/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 (µg/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<br>3.4<br>5.5<br>1.8<br>3.4<br>5.5 | 231<br>231<br>231<br>455<br>455<br>455 | 333<br>294<br>509<br>89<br>182<br>127 | Brown et al. 1994 |

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

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in Water (µg/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 (µg/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 |

**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 |

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.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 |

**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 chloride | - | 72 hr | Reduced progeny formation | 100 | - | - | Wilczok et al. 1994 |
| 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<br>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 | - | - | |

**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 community | S, U | Cadmium chloride | - | 240 hr | Reduced biomas | 1 | - | - | Fernandez-Leborans and Novillo-Villajos 1993 |
| 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<br>250 | 24 hr<br>24 hr | LC50<br>LC50 | 78.1<br>5,270 | 140.8<br>1,026 | -<br>- | 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 |

**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 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 |
| 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 |

**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 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 |
| 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 |

**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 | | | | | |
| 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 |
| 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 |

**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 | | | | | |
| 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 | - | |
| 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 |

**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, *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 |
| 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 |

**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 (<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 |
| 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 |

**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 (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 |
| 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 |

**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 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<br>41<br>71<br>74<br>76 | 48 hr | LC50 | 164<br>99<br>101<br>120<br>65 | 216.8<br>121.1<br>70.71<br>80.56<br>42.47 | -<br>-<br>-<br>-<br>- | Nebeker et al. 1986a |
| Cladoceran (<4 hr), *Daphnia magna* | S, U | Cadmium chloride | 38<br>74 | 48 hr | LC50 | 16<br>146 | 21.15<br>98.01 | -<br>- | Nebeker et al. 1986a |
| Cladoceran (1 d), *Daphnia magna* | S, U | Cadmium chloride | 38<br>71<br>74<br>76 | 48 hr | LC50 | 307<br>135<br>200<br>45 | 405.8<br>94.52<br>134.3<br>29.40 | -<br>-<br>-<br>- | Nebeker et al. 1986a |
| Cladoceran (2 d), *Daphnia magna* | S, U | Cadmium chloride | 38<br>71<br>74<br>76 | 48 hr | LC50 | 131<br>18<br>38<br>21 | 173.2<br>12.60<br>25.51<br>13.72 | -<br>-<br>-<br>- | Nebeker et al. 1986a |
| 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 |

**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 (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 |
| 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 |

**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* | 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 |
| 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 |

**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, M, T | Cadmium chloride | 80-90 | 48 hr | LC50 (20 C) (fed)<br>LC50 (26 C) (fed) | 42<br>6 | 24.49<br>3.498 | -<br>- | 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<br>115<br>230 | 21 days<br>21 days<br>21 days | NOEC survival<br>NOEC brood size<br>NOEC brood size | 3.8<br>7.5<br>7.5 | 3.404<br>4.046<br>2.421 | -<br>-<br>- | 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 |
| 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 |

**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 | | | | | | | | | |
| 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)<br>LC50 (10 C)<br>LC50 (15 C) | 800<br>280<br>60 | -<br>-<br>- | -<br>-<br>- | Gossiaux et al. 1992 |
| 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 |

**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* | S, M, T | Cadmium chloride | 15.3 | 96 hr | LC50 | 12 (pH-5.0)<br>16 (pH=5.5)<br>33 (pH=6.0) | 40.00<br>53.33<br>110.0 | -<br>-<br>- | 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 |
| 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 |

**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 | | | | | |
| 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)<br>(15 C)<br>(25 C)<br>(30 C) | 70,600<br>28,600<br>6,990<br>930 | -<br>-<br>-<br>- | -<br>-<br>-<br>- | Braginskly and Shcherban 1978 |
| 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)<br>8,660 (pH=4.0)<br>10,660 (pH=4.5) | 23,497<br>28,863<br>35,528 | -<br>-<br>- | Mackie 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 | | | | |
| Mayfly, *Ephemerella* sp. | - | Cadmium chloride | 44-48 | 28 days | LC50 | <3.0 | <3.191 | - | Spehar et al. 1978 |
| Mayfly, *Paraleptophiebia 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 | - | |
| 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 |

**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 (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 |
| 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 |

**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 | | | | | | | | | |
| 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 |
| Chinook salmon (alevin), *Oncorhynchus tshawytscha* | - | Cadmium chloride | 23 | 200 hr | LC10 | 21.6 (18-26) | 47.57 | - | Chapman 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 (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 |
| Rainbow trout, *Oncorhynchus mykiss* | - | - | - | 240 hr | LC50 | 7<br>5 | - | - | Kumada et al. 1973 |

**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 (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<br>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)<br>(12 C)<br>(6 C) | 17.3 (10-30)<br>30<br>17.3 (10-30) | 6.816<br>11.82<br>6.816 | -<br>-<br>- | Roch and Maly 1979 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium sulfate | 240 | 234 days | Increased gill diffusion | 2 | 0.6256 | - | Hughes et al. 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 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 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 82 | 178 days | Physiological effects | 4.8 (3.6-6.4) | 3.327 | - | 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, (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<br>300 | 96 hr<br>96 hr | LC50 (fed)<br>LC50 (fed) | 1,300<br>2,600 | 1,028<br>420.6 | -<br>- | 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)<br>0.7 (pH=5.7) | 156.5<br>3.913 | -<br>- | 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)<br>84 (22.8 C)<br>76 (25.7 C)<br>87 (27.9 C) | 60.80<br>40.86<br>36.96<br>42.31 | -<br>-<br>-<br>- | Birge et al. 1985 |

**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<br>NOEC | 41<br>12 | 19.94<br>5.836 | -<br>- | 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)<br>LC50 (male)<br>LC50 (female) | 2,500<br>12,750<br>16,000 | 742.7<br>3,788<br>4,753 | -<br>-<br>- | 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)<br>LC50 (stage 47) | 0.2<br>1.6 | -<br>- | -<br>- | 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)<br>BCF = 24,000 (*Hyalella azteca*) | -<br>- | -<br>- | -<br>- | 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 |

**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 EDTA | - | 28 days | BCF = 252 | - | - | - | George and Coombs 1977 |
| 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 |

**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 | | | | | |
| Eastern oyster, *Crassostrea virginica* | - | Cadmium chloride | - | 2 days | Reduction in embryonic development | 15 | - | - | Zaroogian and Morrison 1981 |
| 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<br>15 | 96 hr<br>96 hr | LC50 (fed)<br>LC50 (fed) | 51.6<br>213 | -<br>- | -<br>- | Hall et al. 1995 |
| Copepod, *Tisbe holothurlae* | - | Cadmium chloride | - | 48 hr | LC50 | 970 | - | - | Moraitou-Apostolopoulou and Verriopoulos 1982 |

**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* | - | - | 15-23 | 17 days | LC50 | 11 | - | - | Nimmo et al. 1977a |
| 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) | - | - | |

**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 (<72 hr), *Americamysis bahia* | F, M, T | - | 30 | 96 hr | LC50 | 85.0 (20°C)<br>28.0 (25°C) | -<br>- | -<br>- | Voyer and Modica 1990 |
| 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 |

**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 | - | 42 days | LC50 | 300 | - | - | Pesch and Stewart 1980 |
| Grass shrimp, *Palaemonetes pugio* | - | Cadmium chloride | 5 | 21 days | LC25 | 50 | - | - | Vernberg et al. 1977 |
| 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 |

**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 | | | | | | | | | |
| 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 |
| 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<br>25 | 21 days<br>21 days | LC50<br>LC50 | 19<br>186 | -<br>- | -<br>- | 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 |

**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 (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 |
| 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 |

**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, M, T | Cadmium chloride | 30 | 80 min | EC50 (sperm- fert.) | 18,000 | - | - | Dinnel et al. 1989 |
| 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<br>7 days | LC50 (fed)<br>NOEC survival and growth | 1,230<br>560 | -<br>- | -<br>- | Hutchinson et al. 1994 |

**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 | | | | | |
| 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 | - | - | |
| 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 |

**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 | 20 | 19 days | LC50 | 540 | - | - | Voyer et al. 1979 |
| 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 |

**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 | | | | | |
| Cunner (adult), *Tautogolabrus adspersus* | - | Cadmium chloride | - | 96 hr | Decreased enzyme activity | 3,000 | - | - | Gould and Karolus 1974 |
| 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.