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# 2000 UPDATE OF AMBIENT WATER QUALITY CRITERIA FOR CADMIUM

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NOTICES

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# FOREWORD

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## Introduction[1]

Cadmium is a relatively rare element that is not essential for any biological process in plants or animals. 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 fresh waters, cadmium sometimes occurs at concentrations of less than 0.01 $\mu$g/L, but in environments impacted by man, concentrations can be several micrograms per liter or greater. 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, fertilizers and pesticides (Hutton 1983).

The impact of cadmium on aquatic organisms depends on a variety of possible chemical forms of cadmium (Callahan et al. 1979), which might have different toxicities and bioconcentration factors. In most well oxygenated fresh waters 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 salt waters with salinities from about 10 to 35 g/kg, cadmium chloride complexes predominate. In both fresh and salt waters, particulate matter and dissolved organic material may bind a substantial portion of the cadmium.

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. More recently, U.S. EPA (1985) expressed cadmium criteria as acid-soluble cadmium (operationally defined as the cadmium that passes through a 0.45 $\mu$m membrane filter after the sample is acidified to pH = 1.5 to 2.0 with nitric acid).

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[1] An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereafter referred to as the Guidelines, is necessary in order to understand the following text, tables, and calculations.

The criteria presented herein supersede previous aquatic life water quality criteria for cadmium (U.S. EPA 1976, 1980, 1985, 1995, 1999a) because these new criteria were derived based on the most recent literature. Whenever adequately justified, 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.

Acute Toxicity to Aquatic Animals

Acceptable data on the acute effects of cadmium in freshwater are available for 43 species of invertebrates, 27 species of fish, one salamander species, and one frog species (Table 1). 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. Hardness is used here as a surrogate for the ions which affect the results of toxicity tests on cadmium.

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 than hard water (Table 1). Data in Table 1 also indicate that cadmium was more toxic to the tubificid worm *Limnodrilus hoffmeisteri*, *Ceriodaphnia reticulata*, *Daphnia pulex*, chinook salmon, goldfish, fathead minnow, green sunfish, striped bass and bluegill in soft than in hard water. Other species tested at different hardness levels (e.g., rainbow trout) did not show the same consistent water hardness to acute toxicity relationship as discussed above, possibly due to differences in the various test conditions. 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, can be used to calculate 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 (U.S. EPA 1999b). Future development of the BLM for cadmium will help better quantify the bioavailable fraction of cadmium.

A tendency for increasing resistance to toxicity with increasing size or age has been reported (Table 1) in the snails, *Amnicola* sp. (Rehwoldt et al. 1973) and *Physa gyrina* (Wier and Walter 1976), the coho salmon (Chapman 1975), and the common carp (Suresh et al. (1993). No such effect was observed with increasing age (Table 1) 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.

Currently, the primary quantitative correlation used to modify metal toxicity estimates is water hardness (viz. the USEPA 1984 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), but it 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.

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 1994), 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. U.S. EPA evaluated the data on dissolved-total relationships from existing data, and then had a number of tests conducted under conditions (static, flow-through, fed, and unfed) that typified standard acute and chronic toxicity tests from which criteria are derived. These studies were used to derive conversion factors (CFs) (Stephan 1995; Lussier et al. 1995; Univ. of Wisconsin-Superior 1995). For certain metals like cadmium, these CFs are hardness dependent.

Based upon the results of these studies, acute freshwater total cadmium concentrations were converted to dissolved concentrations using the factor of 0.97 at a total hardness level of 50 mg/L as $CaCO_3$, 0.94 at a total hardness level of 100 mg/L as $CaCO_3$, and 0.92 at a total hardness level of 200 mg/L as $CaCO_3$. Acute saltwater total cadmium values were converted to dissolved using the factor of 0.994. For the final criterion values, 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, and because of the uncertainty of the conversion factor in tests reporting acute toxicity at higher cadmium concentrations. In cases where only dissolved cadmium was reported in freshwater, conversion to total used the same appropriate factor.

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 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 it's 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 fathead minnow has 29 data points out of the total of 69, and the next most frequent species has just 6 data points.

This analysis of covariance model was fit to the data in Table 1 for the

10 species for which definitive acute 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 1 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 striped bass, the data from Rehwoldt et al. (1972) were not used because the data were too divergent. The slopes for all 10 species ranged from 0.1720 to 1.535, and the pooled slope for these 10 species was 0.9931 (see Table 1b). 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=0.66). The slopes and confidence intervals associated with the 10 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 1.1824, with smaller confidence intervals than for the all *D. magna* 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 1.2049 (see Table 1b). The test for equality of the 10 slopes using the reduced data set (all species but only Chapman *D. magna* data) produced P=0.99. It therefore is reasonable to assume that the slopes for these 10 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 1.2049 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. A plot of the acute effect level (EC50 or LC50) versus total hardness is provided in Figure 1.

The potential for a back-transformation bias associated with the hardness slope adjustment has been noted by Newman (1991). However, the bias discussed by the author reviews bias for single species in least squares regression, rather than ANCOVA used here, so it is not clear how biases may

accumulate (or cancel) with combined species and a combined slope.

The pooled slope of 1.2049 was used to adjust the freshwater acute values in Table 1 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. As stated in the guidelines (Stephen 1985), flow-through measured study data are 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. Only data from Chapman (1975) were used for coho salmon and only data from Rehwoldt et al. (1972) were used for the common carp 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 available acute values for *U. imbecilis*, striped bass and brook trout covered a wide range. 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 some of the Keller unpublished data were used to calculate the SMAV for *U. imbecilis*. The data for brook trout were not used in the calculation of the Final Acute Value. Drummond and Benoit (Manuscript) reported that stress greatly affected the sensitivity of brook trout to cadmium.

The SMAV for freshwater invertebrates ranged from 12.00 µg/L total cadmium for the mussel, *Anodonta coupierana* to 78,579 µg/L total cadmium for the midge, *Chironomus riparius*. Of the fish species tested, the brown trout, *Salmo trutta*, had the lowest SMAV of 1.656 µg/L total cadmium, and the tilapia, *Oreochromis mossambica*, recorded the highest fish SMAV of 11,861 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 3). Salmonids (*Salmo trutta*, *Oncorhynchus kisutch*, *Oncorhynchus mykiss*, and *Oncorhynchus tshawytscha*) are four of the five most sensitive species listed in Table 1, and thus are more sensitive to cadmium than any other freshwater animal species thus far tested (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). The mussel, *Anodonta*

*coupierana*, is the sixth most sensitive species to cadmium, and thus the most sensitive invertebrate species tested thus far (Keller Unpublished).

Genus Mean Acute Values (GMAV) at a hardness of 50 mg/L were then calculated (Table 3) as geometric means of the available freshwater Species Mean Acute Values and ranked. Of the 59 genera for which acute values are available, the most sensitive genus, *Salmo*, is over 47,451 times more sensitive than the most resistant, *Chironomus*. The first through fourth most sensitive genera (and a total n of 59 were considered) in the computation of the final acute value. Because there are 59 GMAVs, the four lowest GMAVs were selected as being closest to the fifth percentile of toxicity, even though the second through the sixth values were also equally as close to the fifth percentile. The sensitivity of these four most sensitive genera are within a factor of 7.2, and except for the fourth genus (*Anodonta*), all are fish. Of the ten most sensitive genera, seven are fish, one is a mussel, one is a cladoceran, and one is a bryozoan (Figure 2; Table 3). Hardness-adjusted acute values are available for more than one species in 10 genera, and the range of SMAVs within each genus is less than a factor of 4.0 for eight of the 10 genera. The ninth genus, *Ptychocheilus*, has two SMAVs that differ by a factor of 146, possibly due to differences in the test conditions between species. The tenth genus, *Morone*, has SMAVs that differ by a factor of 2,954, but only the most sensitive species was used because the two species values are too divergent to use for the genus value.

The freshwater Final Acute Value (FAV) for total cadmium at a hardness of 50 mg/L was calculated to be 5.995 $\mu$g/L total cadmium from the Genus Mean Acute Values in Table 3 using the procedure described in the Guidelines. The Species Mean Acute Values for four salmonids and the striped bass are lower, but the acute value for the brown trout and striped bass are from static tests, whereas flow-through measured tests have been conducted with the remaining three salmonid species. The freshwater Final Acute Value for total cadmium at a hardness of 50 mg/L was lowered to 4.296 $\mu$g/L to protect the important rainbow trout (Table 3). This value is above the SMAV of 1.656 µg/L for the brown trout and 2.535 for striped bass, but below all other SMAVs listed in Table 3 (Figure 2). The resultant freshwater Criterion Maximum Concentration (CMC) at a hardness of 50 mg/L for total cadmium (in $\mu$g/L) = $e^{(1.205[1n(hardness)]-3.949)}$. If the CMC based on total cadmium values is converted to dissolved cadmium using the 0.97 factor at a hardness of 50 mg/L

determined by EPA (Stephan 1995; Lussier et al. 1995; Univ. of Wisconsin-Superior 1995), the freshwater CMC for dissolved cadmium (in $\mu$g/L) = 0.97 [$e^{(1.205[\ln(\text{hardness})]-3.949)}$]. Thus, the 2.1 $\mu$g/L CMC for dissolved cadmium at a hardness of 50 mg/L is below all of the SMAVs but the brown trout presented in Table 3 (Figure 2).

Tests of the acute toxicity of cadmium to saltwater organisms have been conducted with 50 species of invertebrates and 11 species of fish (Table 1). The SMAVs for saltwater invertebrate species range from 41.29 $\mu$g/L for a mysid to 135,000 $\mu$g/L for an oligochaete worm (Tables 1 and 3). The acute values for saltwater polychaetes range from 200 $\mu$g/L for *Capitella capitata* to 14,100 $\mu$g/L for *Neanthes arenaceodentata* (Reish and LeMay 1991), but the larvae of *C. capitata* are 38 times more sensitive than the adults. Saltwater molluscs have Species Mean Acute Values from 227.9 $\mu$g/L for the Pacific oyster to 19,170 $\mu$g/L for the mud snail.

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 $\mu$g/L at salinities of 1, 15, and 35 g/kg, respectively. The LC50 at the very low salinity is in Table 6 and was not used in deriving criteria. Studies with *Americamysis bahia* (formerly *Mysidopsis 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 $\mu$g/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 $\mu$g/L for the striped bass (at a salinity of 1 g/kg) to 50,000 $\mu$g/L for the sheepshead minnow. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, Voyer (1975) found that the 96-hr LC50 at a temperature of 18-20°C and a salinity of 32 g/kg was about one-half what it was 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 1 and 6.

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 3). 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 *Capitella capitata*, only data from Martin et al. (1981) and Nelson et al. (1976) were used for *Mytilus edulis*, only data from Sullivan et al. (1983) were used for *Eurytemora affinis,* only data from Cripe (1994) were used for *Penaeus 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.

The saltwater Final Acute Value for total cadmium calculated from the Genus Mean Acute Values in Table 3 is 80.55 $\mu$g/L. This Final Acute Value is below the SMAV for the mysid, *Mysidopsis bigelowi* (110 $\mu$g/L), but is aproximately three percent above the American lobster (78 $\mu$g/L), approximately seven percent higher than the striped bass (75.0 $\mu$g/L), and approximately 95 percent above the SMAV for the mysid, *Americamysis bahia* (41.29 $\mu$g/L, geometric mean of two flow-through measured tests). The resultant saltwater Criterion Maximum Concentration (CMC) for total cadmium is 40.28 $\mu$g/L (FAV/2 or 80.55 $\mu$g/L/2). If the total cadmium CMC is converted to dissolved cadmium using the 0.994 factor determined experimentally by EPA, the saltwater CMC for dissolved cadmium is 40.03 $\mu$g/L. The resultant 40.03 $\mu$g/L CMC for dissolved cadmium is below all of the saltwater SMAVs presented in Table 3 (Figure 3).

Chronic Toxicity to Aquatic Animals

Acceptable chronic toxicity tests have been conducted on cadmium in freshwater with 21 species, including seven invertebrates and 14 fishes in 16 genera. Several related values are in Table 6. Among the unused values in

Table 6, 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 $\mu$g/L. Bertram and Hart (1979) and Ingersoll and Winner (1982) found chronic toxicity to *Daphnia pulex* at less than 1 and 10 $\mu$g/L, respectively. The 200-hr LC10 of 0.7 $\mu$g/L obtained with rainbow trout (Table 6) 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 $\mu$g/L or less (Table 6). These species include decomposers (Giesy 1978), protozoans (Fernandez-Leborans and Noville-Villajes 1993; Niederlehner et al. 1985), *Ceriodaphnia dubia* (Winner 1988; Zuiderveen and Birge 1997), *D. magna* (Enserink et al. 1993; Winner and Whitford 1987), zooplankton (Lawrence and Holoka 1987), crayfish (Thorp et al. 1979), amphipods (Borgmann et al. 1991; Phipps et al. 1995), copepods and annelids (Giesy et al. 1979), 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 $\mu$g/L measured cadmium concentrations in addition to a laboratory water control at 25°C. The NOEC and LOEC were 10 and 19 $\mu$g/L cadmium, respectively, with a resultant chronic value of 14 $\mu$g/L cadmium (Table 2).

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 $\mu$g/L cadmium among the three tests) and a control (0.08 $\mu$g/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 $\mu$g/L cadmium at hardness levels of 53, 103 and 209 mg/L, respectively (Table 2). 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 $\mu$g/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 $\mu$g/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 $\mu$g/L cadmium, and the reproductive LOEC was 10.0 $\mu$g/L cadmium. However, a more sensitive endpoint was the length of the 5$^{th}$ and 6$^{th}$ broods of neonates, where the 25-day NOEC and LOEC were estimated to be 0.5 and 1.0 $\mu$g/L cadmium, respectively. The resultant chronic value was 0.7071 $\mu$g/L cadmium (Table 2).

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 $\mu$g/L cadmium. Reproduction was significantly reduced at the lowest measured exposure concentration of 1.86 $\mu$g/L cadmium. Thus, the reproductive NOEC and LOEC were <1.86 and 1.86 $\mu$g/L cadmium, respectively, with a chronic value of <1.86 $\mu$g/L cadmium (Table 2).

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 $\mu$g/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 $\mu$g/L cadmium. Second generation fry development was significantly affected when the parents were exposed 1.77 $\mu$g/L cadmium, but not when exposed to 0.47 $\mu$g/L cadmium. 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 a statistically derived NOEC and LOEC of 3.39 and 5.48 $\mu$g/L cadmium. The resultant chronic value was 4.310 $\mu$g/L cadmium

(Table 2).

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 $\mu$g/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 $\mu$g/L cadmium, respectively, with a resultant chronic value of 16.49 $\mu$g/L cadmium (Table 2).

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 2). They reported a chronic value of 10.0 $\mu$g/L cadmium, which when coupled with their 96-hour LC50 of 13.2 $\mu$g/L cadmium, gives an acute-chronic ratio of 1.320.

Cope et al. (1994) examined the sublethal responses of juvenile bluegills exposed to cadmium under flow-through conditions at an average total hardness of 134 mg/L (as $CaCO_3$) and temperature of 21.7°C. The fish were exposed to a control (0.02 $\mu$g/L cadmium) and seven measured cadmium concentrations that ranged from 2.8 to 32.3 $\mu$g/L. At the end of the 28-day test, test fish survival or growth was not adversely affected, resulting in a NOEC of >32.3 $\mu$g/L cadmium and a chronic value of >32.3 $\mu$g/L cadmium (Table 2).

Ingersoll and Kemble (unpublished) investigated the chronic toxicity of cadmium to the amphipod *Hyalella azteca.* The organisms were exposed under flow-through measured conditions at a mean temperature of 23°C and a total hardness of 280 mg/L (as $CaCO_3$), and 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, 0.31, 0.51, 2.0 and 3.5 $\mu$g/L for 42 days. The most sensitive endpoint was survival, with an NOEC and LOEC of 0.5 and 2.0 $\mu$g/L cadmium, respectively, after both 28 and 42 days of exposure. The resultant chronic value was 1.000 $\mu$g/L total cadmium (Table 2).

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 ml 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 16.4 $\mu$g/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 16.4 $\mu$g/L cadmium, respectively (Table 2). The resultant chronic value was 9.753 $\mu$g/L total cadmium.

Chronic values are available over a wide range of hardness for two species (Table 2). 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 2 for the two 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 2 either did not meet these criteria or did not show any hardness-toxicity trend probably due to differences in exposure methods, species age, etc.). The slopes for the two species ranged from 0.9786 to 1.003, and the pooled slope for these two species was 0.9917 (Table 2b). A plot of the chronic effect level versus total hardness is provided in Figure 4.

The slope of 0.9917 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 were then calculated, and from these, the sixteen Genus Mean Chronic Values were calculated and ranked (Table 3b).

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 seemed appropriate since a number of chronic tests have been conducted with a large variety of species. Thus, the freshwater Final Chronic Value for total cadmium is 0.0861 $\mu$g/L at a hardness of 50 mg/L, and the Final

Chronic Value (in $\mu$g/L) = $e^{(0.9917[1n(hardness)]-6.332)}$. For dissolved cadmium, the Final Chronic value is 0.0809 $\mu$g/L (0.94 x 0.0861 $\mu$g/L) at a hardness of 50 mg/L, or = 0.94 [$e^{(0.9917[1n(hardness)]-6.332)}$]. 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 2c and 3). These ratios do not seem to follow any of the patterns (Table 3) 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.

Three chronic toxicity tests have been conducted with the saltwater invertebrate, *Americamysis bahia*, formerly classified as *Mysidopsis bahia* (Table 2). 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 $\mu$g/L, 84 percent at the next lower test concentration of 6.4 $\mu$g/L, and 95 percent in the controls. No unacceptable effects were observed at 6.4 $\mu$g/L or any lower concentration. The chronic toxicity limits, therefore, are 6.4 and 10.6 $\mu$g/L, with a chronic value of 8.237 $\mu$g/L. The 96-hr LC50 was 15.5 $\mu$g/L, resulting in an acute-chronic ratio of 1.882.

Another life-cycle test was conducted on cadmium with *Americamysis 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. Manuscript). All organisms died in 28 days at 23 $\mu$g/L. At 10 $\mu$g/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 $\mu$g/L. Thus, the chronic limits for this study are 5.1 and 10 $\mu$g/L for a chronic value of 7.141 $\mu$g/L. The LC50 at 21°C and salinity of 30 g/kg was 110 $\mu$g/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 6). 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 *Americamysis 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. 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 treatment group, the lowest exposure concentration 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 (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 3) 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 8.846 μg/L is obtained, or 8.793 μg/L dissolved cadmium (0.994 x 8.846 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 4). 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 in unknown, but is probably minor at least in the case of Conway (1978) who used a medium patterned after natural Lake Michigan water. Because the lowest toxicity values for fish and invertebrate species are lower than the lowest values for plants, water quality criteria which protect freshwater animals should also protect freshwater plants.

Toxicity values are available for five species of saltwater diatoms and two species of macroalgae (Table 4). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 60 $\mu$g/L for *Ditylum brightwelli* to 22,390 $\mu$g/L for *Phaeodactylum tricornutum*, the most resistant to cadmium. The brown macroalga (kelp) exhibited mid-range sensitivity to cadmium, with an EC50 of 860 $\mu$g/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 $\mu$g/L. This plant is more resistant than the chronically most sensitive animal species tested. Therefore, water quality criteria for cadmium that protect saltwater animals should also protect saltwater plants.

Bioaccumulation

Bioconcentration factors (BCFs) for cadmium in fresh water (Table 5) 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; Sangalang and Freemen 1979). Also, cadmium residues in fish reach steady-state only after exposure periods greatly exceeding 28 days (Benoit et al. 1976; Sangalang and Freeman 1979). *Daphnia 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, *Viviparus georgianus*, but not for the mussel,

*Elliptio complanata*. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by *Daphnia 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 6). 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 5). 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 6) as well as 1,220, 1,830 and 2,150 (Table 5). 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 5 and 6). 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 6) was bioconcentrated at twice the rate of inorganic cadmium (Table 5). 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 5 and 6). 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 6), 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 5 and 6).

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 Table 4. 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

A number of the values in Table 6 have already been discussed. When possible, the freshwater acute effect concentration has been adjusted to a hardness of 50 using the pooled slope. Cadmium-binding proteins were isolated from *Amoeba proteus* (Al-atia, 1978, 1980) and rainbow trout (Roberts et al. 1979). The cumulative mortality resulting from exposure to cadmium for more than 96 hours is clearly evident from the studies with phytoplankton (Findlay et al. 1996; Fargasova 1993), duckweed (Outridge 1992), protozoa (Niederlehner 1985), zooplankton (Lawrence and Holoka (1987), snails (Spehar et al. 1978), zebra mussels (Kraak et al. 1992), 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).

Nimmo et al. (1977a) in studies with the mysid, *Americamysis bahia*, reported a 96-hr LC50 of 15.5 $\mu$g/L (Table 1) and a 17-day LC50 of 11 $\mu$g/L (Table 6) at 25 to 28°C and salinity of 15 to 23 g/kg. In another series of studies with this mysid (Gentile et al. 1982), the 96-hr LC50 was 110 $\mu$g/L (Table 1) and the 16-day LC50 was 28 $\mu$g/L (Table 6) at 20 °C and salinity of 30g/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 6). Significant reduction in gill tissue respiratory rate was reported for the cunner after a 30-day exposure to 50 $\mu$g/L (MacInnes et al. 1977). Dawson et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 0.5 $\mu$g/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 $\mu$g/L.

Unused Data

Some data on the effects of cadmium on aquatic organisms were not used because the studies were conducted with species that are not resident in North America, e.g., 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, 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 (193), 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),and Zou and Bu (1994). Brown and Ahsanullah (1971) conducted tests with a brine shrimp, which species are too atypical to be used in

deriving national criteria.

Data were also not used if 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). Reviews by 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), Eisler 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), and Wong (1987) only contain data that have been published elsewhere.

Data were not used if the organisms were exposed to cadmium in food or by injection or gavage (e.g., 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).

A number of studies of cadmium toxicity examined physiological or behavioral effects but provided no interpretable concentration, time, response data, and some papers described effects of only a single, often lethal, concentration. Included in such studies are those of 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), and Xue and Sigg (1998).

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), and Sobhan and Sternberg (1999) presented no useable data on cadmium toxicity or bioconcentration.

Papers that dealt with the selection, adaptation, or acclimation of organisms for increased resistance to cadmium were not used, e.g., 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), and 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). Data in publications such as 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), and Zhang et al. (1992) were not used because either the materials, methods, or results were insufficiently described. 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. Algal studies were not used if they were not conducted in an appropriate medium (Stary and Kratzer 1982; Stary et al. 1983) or if the medium contained too much of a complexing agent such as EDTA (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; 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). Some papers were omitted because of questionable treatment of test organisms or inappropriate test conditions or methodology (e.g., 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; Ridlington et al. 1981; Sunda et al. 1978; Wikfors and Ukeles 1982).

Data on bioconcentration by aquatic organisms were not used if the test was conducted in distilled water, was not long enough, was not flow-through, or if the concentrations in water were not adequately measured (e.g., 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 for cadmium are available for species in 59 genera and hardness adjusted values range from 1.656 μg/L for brown trout to 78,579 μg/L for a midge. The antagonistic effect of hardness on acute toxicity has been demonstrated with 10 species. Chronic tests have been conducted on cadmium with 14 freshwater fish species and seven invertebrate species with hardness adjusted Species Mean Chronic Values ranging from 0.1811 μg/L for *Hyalella azte*ca to 34.19 μg/L for *Ceriodaphnia dubia*. Acute-chronic ratios are available for eight 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 fresh water range from 7 to 6,910 for invertebrates and from 3 to 2,213 for fishes.

Saltwater cadmium species mean acute values for 11 fish species range from 75.0 μg/L for striped bass to 50,000 μg/L for sheepshead minnow. Species Mean Acute values for 50 species of invertebrates range from 41.29 μg/L for a mysid to 135,000 μg/L for an oligochaete worm. The acute toxicity of cadmium generally increases as salinity decreases. The effect of temperature seems to be species-specific. Two life-cycle tests with *Americamysis bahia* under different test conditions resulted in similar chronic values of 8.237 and 7.141 μg/L, but the acute-chronic ratios were 1.882 and 15.40, respectively. A third chronic test with *Americamysis bahia* gave a slightly lower chronic value, possibly due to the unexpected temperature (14-26 °C) fluctuation. The acute values appear to reflect effects of salinity and temperature, whereas the few available chronic values apparently do not. A life-cycle test with *Mysidopsis bigelowi* also resulted in a chronic value of 7.141 μg/L and an acute-chronic ratio of 15.40. Studies with microalgae and macroalgae revealed effects at 2 to 22,390 μg/L.

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. Cadmium mortality is cumulative for exposure periods beyond four days. Chronic cadmium exposure resulted in significant effects on the growth of bay scallops

at 78 $\mu$g/L.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration (in $\mu$g/L) of dissolved cadmium does not exceed the numerical value given by 0.94 $[e^{(0.9917[1n(hardness)]-6.332)}]$ more than once every three years on the average, and if the one-hour average dissolved concentration (in $\mu$g/L) does not exceed the numerical value given by 0.97 $[e^{(1.205[1n(hardness)]-3.949)}]$ 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 0.08, 0.16 and 0.32 $\mu$g/L, respectively, and the one-hour average dissolved concentrations are 2.1, 4.8, and 11 $\mu$g/L. If brown trout are as sensitive as some data indicate, they may not be protected by this criterion.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average dissolved concentration of cadmium does not exceed 8.8 $\mu$g/L more than once every three years on the average and if the one-hour average dissolved concentration does not exceed 40 ug/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 one-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

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 may contribute to cadmium loading of organisms, possibly through ingestion.

The recommended exceedence frequency of three years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to cadmium exceeds the criterion. Stressed systems, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. 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 1985).

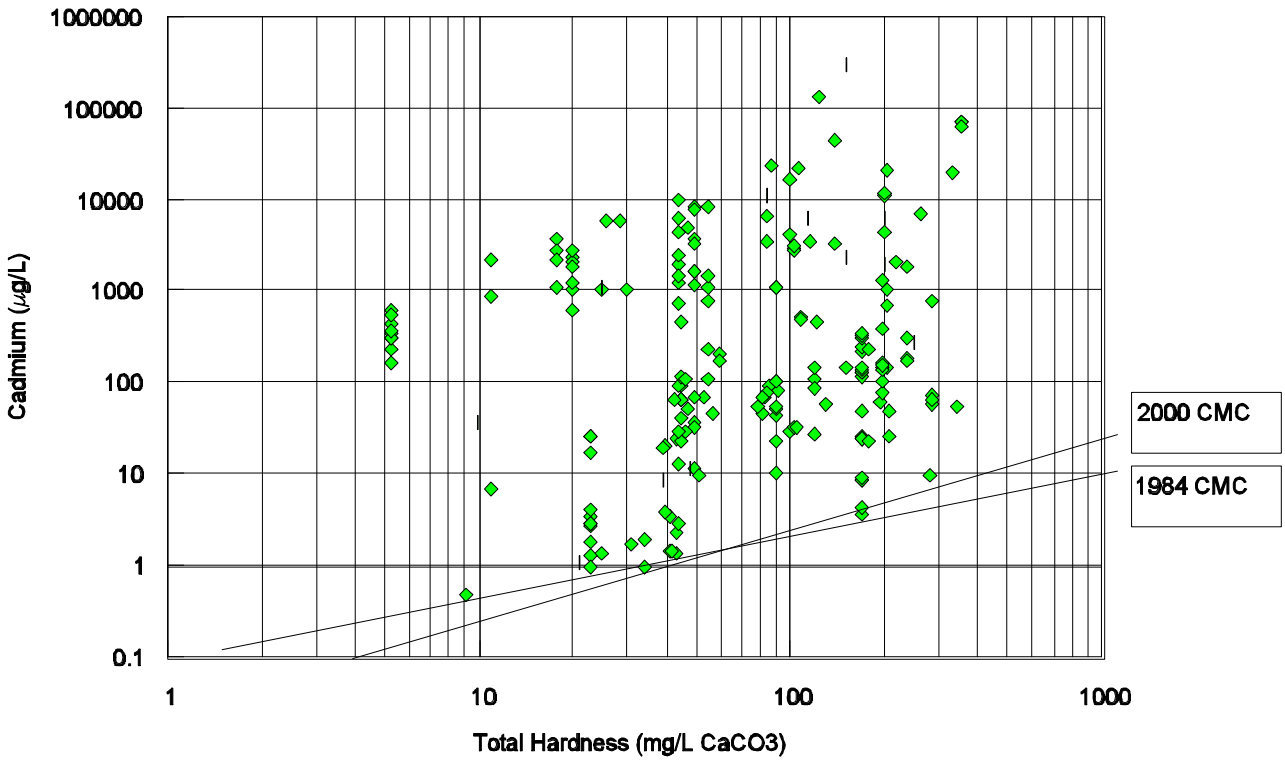


Figure 1. Comparison of All Table 1 Freshwater Acute Toxicity Test EC50s and LC50s with the Hardness Slope Derived CMC.

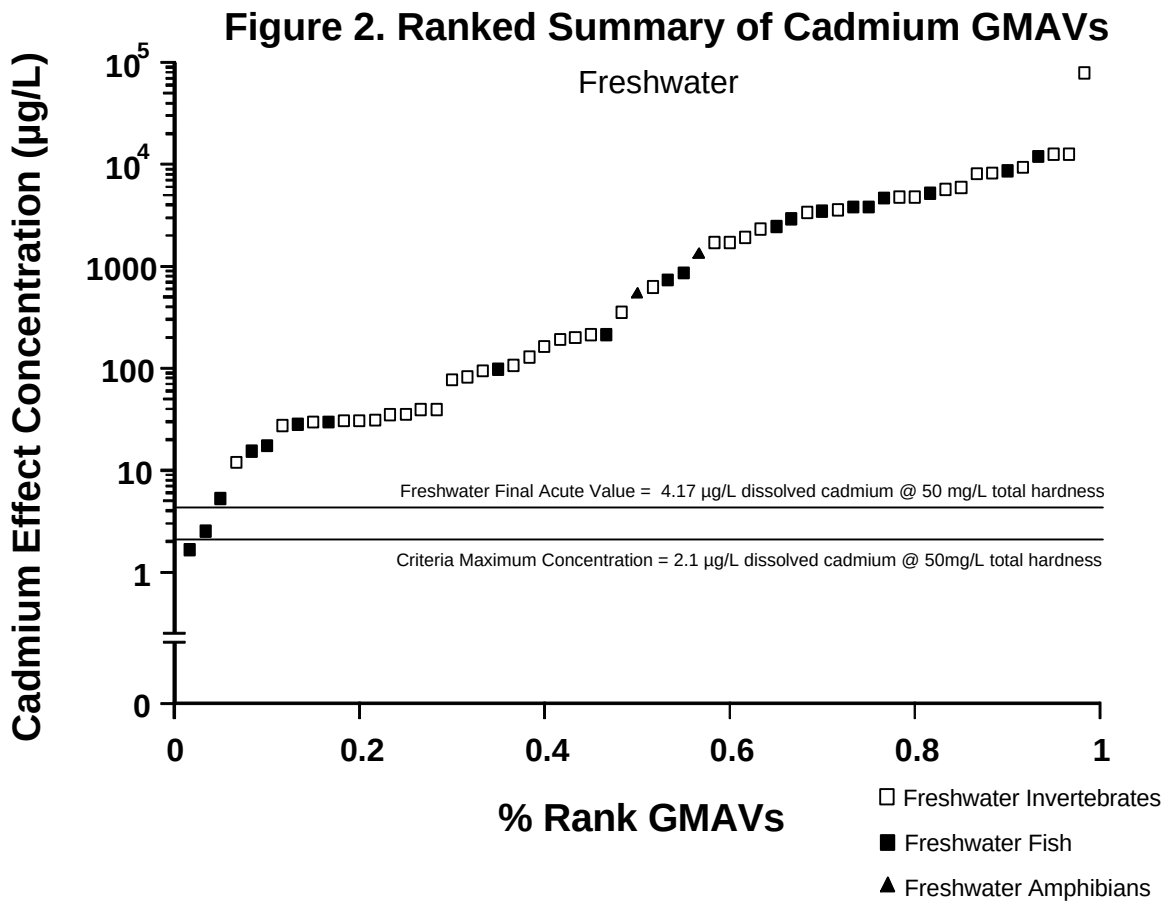
Figure 2. Ranked Summary of Cadmium GMAVs
Freshwater
Cadmium Effect Concentration (µg/L)
10^5
10^4
1000
100
10
1
0
0
0.2
0.4
0.6
0.8
1
% Rank GMAVs
Freshwater Final Acute Value = 4.17 µg/L dissolved cadmium @ 50 mg/L total hardness
Criteria Maximum Concentration = 2.1 µg/L dissolved cadmium @ 50mg/L total hardness
Freshwater Invertebrates
Freshwater Fish
Freshwater Amphibians

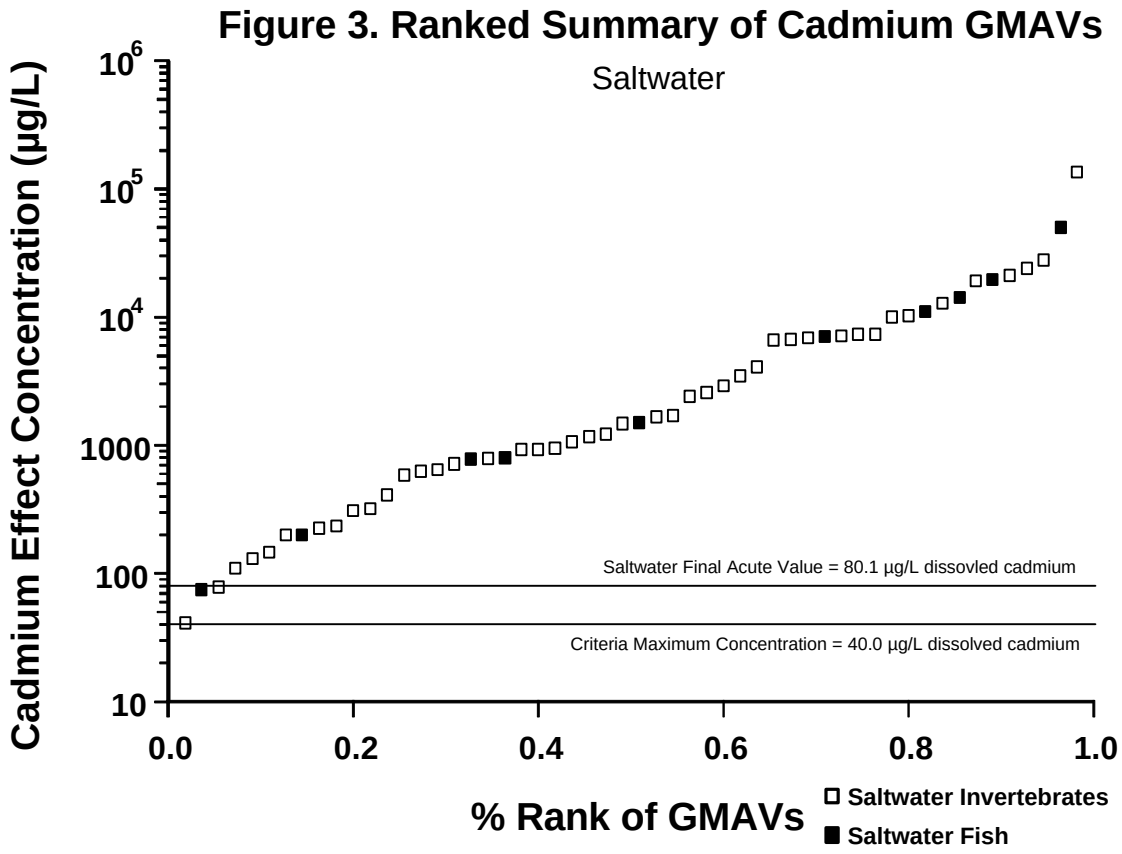
Figure 3. Ranked Summary of Cadmium GMAVs
Saltwater
Cadmium Effect Concentration (µg/L)
10^6
10^5
10^4
1000
100
10
0.0
0.2
0.4
0.6
0.8
1.0
% Rank of GMAVs
Saltwater Final Acute Value = 80.1 µg/L dissovled cadmium
Criteria Maximum Concentration = 40.0 µg/L dissolved cadmium
Saltwater Invertebrates
Saltwater Fish

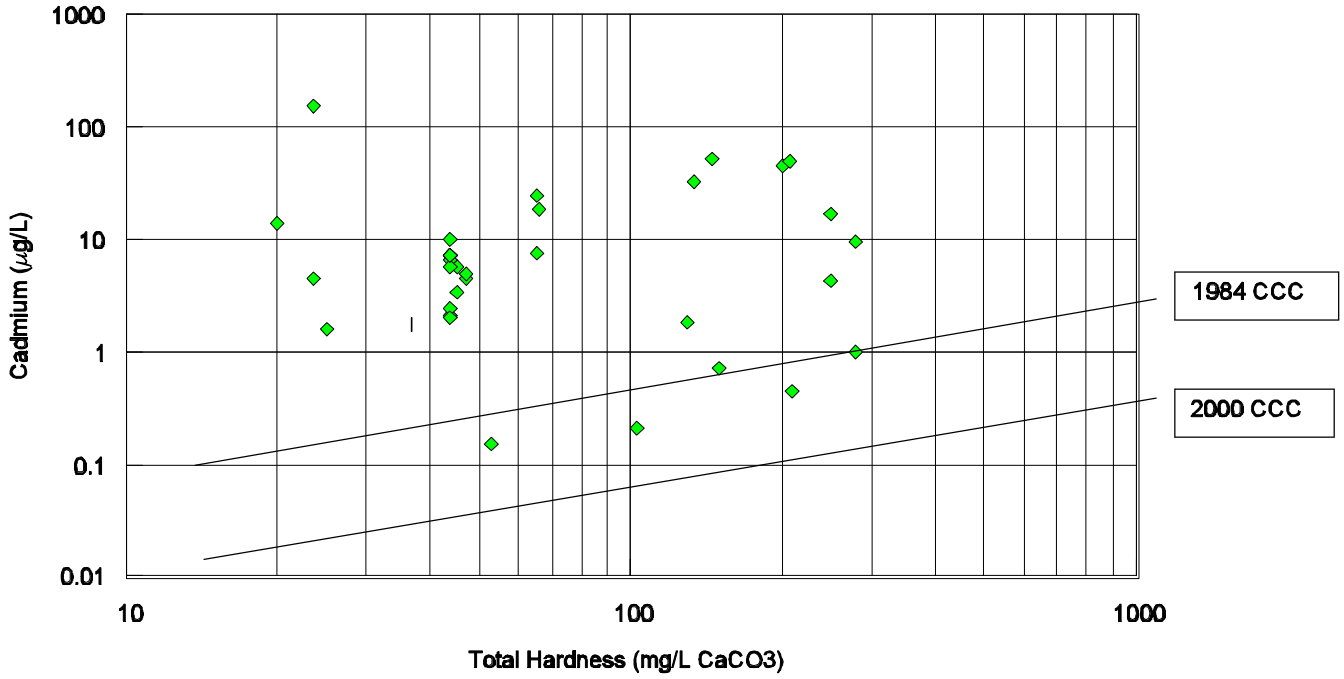


Figure 4. Comparison of All Table 2 Freshwater Chronic Values with the Hardness Slope Derived CCC.

## Figure 5. Chronic Toxicity of Cadmium to Aquatic Animals

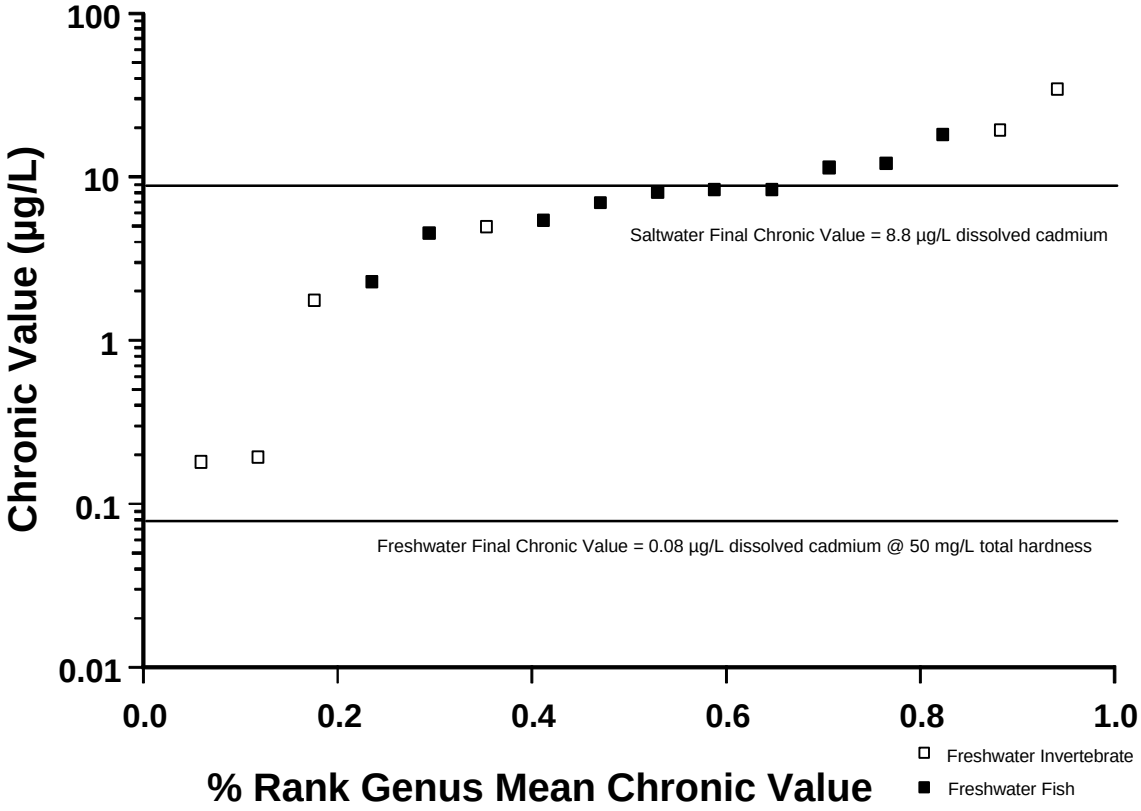

Table 1a. Acute Toxicity of Cadmium to Aquatic Animals

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | LC50 or EC50 (Total $\mu$g/L)[b] | LC50 or EC50 (Diss. $\mu$g/L) | LC50 or EC50 Adj. to Th=50 (Total $\mu$g/L) | Species Mean Acute Value at TH=50 (Total $\mu$g/L)[c] | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | | FRESHWATER SPECIES | | | | |
| Planarian, *Dendrocoelum lacteum* | R, M, T | Cadmium chloride | 87 | 24,702 | 23,220 | **12,673** | 12,673 | Ham et al. 1995 |
| Worm (adult), *Lumbriculus variegatus* | S, M, T | Cadmium nitrate | 280-300 | 780 | - | **93.81** | 93.81 | Schubauer-Berigan et al. 1993 |
| Tubificid worm, *Branchiura sowerbyi* | S, M | Cadmium sulfate | 5.3 | 240 | - | **3,586** | 3,586 | Chapman et al. 1982a |
| Tubificid worm, *Limnodrilus hoffmeisteri* | S, M | Cadmium sulfate | 5.3 | 170 | - | 2,540 | - | Chapman et al. 1982a |
| Tubificid worm (30-40 mm) *Limnodrilus hoffmeisteri* | F, M, T | - | 152 | 2,400 | - | **628.6** | 628.6 | Williams et al. 1985 |
| Tubificid worm, *Quistadrilus multisetosus* | S, M | Cadmium sulfate | 5.3 | 320 | - | **4,781** | 4,781 | Chapman et al. 1982a |
| Tubificid worm, *Rhyacodrilus montana* | S, M | Cadmium sulfate | 5.3 | 630 | - | **9,413** | 9,413 | Chapman et al. 1982a |
| Tubificid worm, *Spirosperma ferox* | S, M | Cadmium sulfate | 5.3 | 350 | - | **5,230** | 5,230 | Chapman et al. 1982a |
| Tubificid worm, *Spirosperma nikolskyi* | S, M | Cadmium sulfate | 5.3 | 450 | - | **6,724** | 6,724 | Chapman et al. 1982a |
| Tubificid worm, *Stylodrilus heringlianus* | S, M | Cadmium sulfate | 5.3 | 550 | - | **8,218** | 8,218 | Chapman et al. 1982a |
| Tubificid worm *Tubifex tubifex* | S, U | Cadmium chloride | - | 1,032 | - | - | - | Fargasova 1994a |
| Tubificid worm, *Tubifex tubifex* | S, M | Cadmium sulfate | 5.3 | 320 | - | **4,781** | 4,781 | Chapman et al. 1982a |
| Tubificid worm, *Varichaeta pacifica* | S, M | Cadmium sulfate | 5.3 | 380 | - | **5,678** | 5,678 | Chapman et al. 1982a |
| Worm, *Nais* sp. | S, U | - | 50 | 1,700 | - | **1,700** | 1,700 | Rehwoldt et al. 1973 |
| Leech, *Glossiponia* | R, M, T | Cadmium | 122.8 | 480 | - | **162.6** | 162.6 | Brown and Pascoe 1988 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Snail (embryo), *Amnicola* sp. | S, U | - | 50 | 3,800 | - | 3,800 | - | Rehwoldt et al. 1973 |
| Snail (adult), *Amnicola* sp. | S, U | - | 50 | 8,400 | - | 8,400 | - | Rehwoldt et al. 1973 |
| Snail, *Aplexa hypnorum* | F, M | Cadmium chloride | 45.3 | 93 | - | **104.7** | - | Holcombe et al. 1984 |
| Snail (adult), *Aplexa hypnorum* | F, M, T | Cadmium chloride | 44.4 | 93 | - | **107.3** | 106.0 | Phipps and Holcombe 1985 |
| Snail (adult), *Physa gyrina* | S, M | - | 200 | 1,370 | - | 257.8[d] | - | Wier and Walter 1976 |
| Snail (immature), *Physa gyrina* | S, M | - | 200 | 410 | - | **77.15** | 77.15 | Wier and Walter 1976 |
| Mussel (juvenile), *Utterbackia imbecilis* | S, M | - | 90 | 1,150 | - | 566.4[e] | - | Keller Unpublished |
| Mussel (juvenile), *Utterbackia imbecilis* | S, M | - | 90 | 1,120 | - | 551.6[e] | - | Keller Unpublished |
| Mussel, *Utterbackia imbecilis* | S, M, T | Cadmium chloride | 39 | 9 | - | **12.14** | - | Keller and Zam 1991 |
| Mussel, *Utterbackia imbecilis* | S, M, T | Cadmium chloride | 80-100 | 107 | - | **52.70** | - | Keller and Zam 1991 |
| Mussel (juvenile), *Utterbackia imbecilis* | S,M,T | - | 90 | 44 | - | **21.67** | - | Keller Unpublished |
| Mussel (juvenile), *Utterbackia imbecilis* | S,M,T | - | 92 | 82 | - | **39.33** | - | Keller Unpublished |
| Mussel (juvenile), *Utterbackia imbecilis* | S,M,T | - | 86 | 93.0 | - | **48.38** | 30.50 | Keller Unpublished |
| Mussel, | S,M,T | - | 82 | 46.4 | - | **25.57** | - | Keller Unpublished |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Mussel, *Actinonaia pectorosa* | S,M,T | - | 84 | 69 | - | **36.93** | 30.73 | Keller Unpublished |
| Mussel, *Anodonta coupierana* | S,M,T | - | 50 | 12 | - | **12.00** | 12.00 | Keller Unpublished |
| Mussel, *Lampsilis straminea claibornensis* | S,M,T | - | 50 | 38 | - | **38.00** | 38.00 | Keller Unpublished |
| Mussel, *Lampsilis teres* | S,M,T | - | 50 | 33 | - | **33.00** | 33.00 | Keller Unpublished |
| Cladoceran, *Alona affinis* | S, U | Cadmium nitrate | 109 | 546 | - | **213.5** | 213.5 | Ghosh et al. 1990 |
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, U | Cadmium chloride | 80-100 | 54 | - | **26.60** | - | Britton et al. 1996 |
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | R, M, T | Cadmium chloride | 70-90 | 54.5 | - | **30.94** | - | Diamond et al. 1997 |
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, U | Cadmium chloride | 80-100 | 55.9 | - | **27.53** | 28.29 | Lee et al. 1997 |
| Cladoceran, *Ceriodaphnia reticulata* | S, U | - | 45 | 66 | - | 74.93 | - | Mount and Norberg 1984 |
| Cladoceran (<24 hr) *Ceriodaphnia reticulata* | S, U | Cadmium chloride | 240 | 184 | - | 27.80 | - | Elnabarawy et al. 1986 |
| Cladoceran (<6 hr) *Ceriodaphnia reticulata* | S, U | Cadmium chloride | 120 | 110 | - | 38.31 | 43.05 | Hall et al. 1986 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium chloride | - | <1.6[h] | - | - | - | Anderson 1948 |
| Cladoceran, | S, U | Cadmium | 45 | 65 | - | 73.80 | - | Biesinger and |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Daphnia magna* | S, U | Cadmium nitrate | - | 27.07 | - | - | - | Canton and Adema 1978 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium nitrate | - | 28.04 | - | - | - | Canton and Adema 1978 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium nitrate | - | 35.13 | - | - | - | Canton and Adema 1978 |
| Cladoceran, *Daphnia magna* | R, M | Cadmium Chloride | 100 | 30 | - | 13.01 | - | Canton and Slooff 1982 |
| Cladoceran, *Daphnia magna* | S, U | - | 45 | 118 | - | 134.0 | - | Mount and Norberg 1984 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium chloride | 120 | 28.3 | - | 9.855 | - | Hall et al. 1986 |
| Cladoceran (<24 hr), *Daphnia magna* | S, U | Cadmium chloride | 240 | 178 | - | 26.89 | - | Elnabarawy et al. 1986 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium sulfate | 240 | 1,880 | - | 284.0 | - | Khangarot and Ray 1989a |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 3.6 (genotype A) | - | 0.8240 | - | Baird et al. 1991 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 9.0 (genotype A-1) | - | 2.060 | - | Baird et al. 1991 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 9.0 (genotype A-2) | - | 2.060 | - | Baird et al. 1991 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 4.5 (genotype B) | - | 1.030 | - | Baird et al. 1991 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 27.1 (genotype E) | - | 6.203 | - | Baird et al. 1991 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 115.9 (genotype S-1) | - | 26.53 | - | Baird et al. 1991 |
| Cladoceran (<24 hr), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 24.5 (Clone F) | - | 5.608 | - | Stuhlbacher et al. 1992 |
| Cladoceran (<24 hr), | S, M, T | Cadmium chloride | 160-180 | 129.4 (Clone S-1) | - | 29.62 | - | Stuhlbacher et al. 1992 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Daphnia magna* | S, M, T | Cadmium chloride | 10 | 37.9 | - | 263.5 | - | Hickey and Vickers 1992 |
| Cladoceran (3 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 25.4 (Clone F) | - | 5.814 | - | Stuhlbacher et al. 1993 |
| Cladoceran (3 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 228.8 (Clone S-1) | - | 52.37 | - | Stuhlbacher et al. 1993 |
| Cladoceran (6 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 49.1 (Clone F) | - | 11.24 | - | Stuhlbacher et al. 1993 |
| Cladoceran (6 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 250.1 (Clone S-1) | - | 57.24 | - | Stuhlbacher et al. 1993 |
| Cladoceran (10 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 131.2 (Clone F) | - | 30.03 | - | Stuhlbacher et al. 1993 |
| Cladoceran (10 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 319.3 (Clone S-1) | - | 73.08 | - | Stuhlbacher et al. 1993 |
| Cladoceran (20 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 139.9 (Clone F) | - | 32.02 | - | Stuhlbacher et al. 1993 |
| Cladoceran (20 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 326.3 (Clone S-1) | - | 74.69 | - | Stuhlbacher et al. 1993 |
| Cladoceran (30 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 146.7 (Clone F) | - | 33.58 | - | Stuhlbacher et al. 1993 |
| Cladoceran (30 d), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 355.3 (Clone S-1) | - | 81.32 | - | Stuhlbacher et al. 1993 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium chloride | - | 360 | - | - | - | Fargasova 1994a |
| Cladoceran, *Daphnia magna* | S, U | Cadmium sulfate | 250 | 280 | - | 40.27 | - | Crisinel et al. 1994 |
| Cladoceran (<24 hr), *Daphnia magna* | S, U | Cadmium chloride | 160-180 | 9.5 | - | 2.174 | - | Guilhermino et al. 1996 |
| Cladoceran, | S, M, T | Cadmium | 46.1 | 112 | 104 | 123.5 | - | Barata et al. 1998 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 90.7 | 106 (clone S-1) | 91.4 | 51.72 | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 179 | 233 (clone S-1) | 179 | 50.12 | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 46.1 | 30.1 (clone A) | 27.8 | 33.19 | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 90.7 | 23.4 (clone A) | 20.2 | 11.42 | - | Barata et al. 1998 |
| Cladoceran, *Daphnia magna* | S, M, T | Cadmium sulfate | 179 | 23.6 (clone A) | 18.1 | 5.076 | - | Barata et al. 1998 |
| Cladoceran, (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 51 | 9.9 | - | 9.667 | - | Chapman et al. Manuscript |
| Cladoceran, (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 104 | 33 | - | 13.65 | - | Chapman et al. Manuscript |
| Cladoceran, (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 105 | 34 | - | 13.91 | - | Chapman et al. Manuscript |
| Cladoceran, (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 197 | 63 | - | 12.07 | - | Chapman et al. Manuscript |
| Cladoceran, (<24 hr) *Daphnia magna* | S, M, T | Cadmium Chloride | 209 | 49 | - | 8.745 | - | Chapman et al. Manuscript |
| Cladoceran, (<24 hr) *Daphnia magna* | F, M, T | Cadmium Chloride | 130 | 58 | - | **18.34** | 18.34 | Attar and Maly 1982 |
| Cladoceran, *Daphnia pulex* | S, U | Cadmium nitrate | - | 93.45 | - | - | - | Canton and Adema 1978 |
| Cladoceran, *Daphnia pulex* | S, U | Cadmium chloride | 57 | 47 | - | **40.14** | - | Bertram and Hart 1979 |
| Cladoceran, *Daphnia pulex* | S, U | - | 45 | 68 | - | **77.20** | - | Mount and Norberg 1984 |
| Cladoceran | S, U | Cadmium | 240 | 319 | - | **48.19** | - | Elnabarawy et al. 1986 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Daphnia pulex* | S, U | Cadmium chloride | 120 | 89.4 | - | **31.13** | - | Hall et al. 1986 |
| Cladoceran (<24 hr), *Daphnia pulex* | S, M, T | Cadmium chloride | 53.5 | 70.1 | - | **64.61** | - | Stackhouse and Benson 1988 |
| Cladoceran, *Daphnia pulex* | S, U | Cadmium chloride | 80-90 | 78.3 | - | **41.31** | 48.12 | Roux et al. 1993 |
| Cladoceran, *Moina macrocopa* | S, U | Cadmium chloride | 80-84 | 71.25 | - | **39.26** | 39.26 | Hatakeyama and Yasuno 1981b |
| Cladoceran, *Simocephalus serrulatus* | S, M | Cadmium chloride | 11.1 | 7.0 | - | **42.92** | - | Giesy et al. 1977 |
| Cladoceran, *Simocephalus serrulatus* | S, M | Cadmium chloride | 39-48 | 24.5 | - | **29.14** | 35.36 | Spehar and Carlson 1984a,b |
| Cladoceran, *Simocephalus vetulus* | S, U | - | 45 | 24 | - | **27.25** | 27.25 | Mount and Norberg 1984 |
| Copepod, *Cyclops varicans* | S, U | Cadmium nitrate | 109 | 493 | - | **192.8** | 192.8 | Ghosh et al. 1990 |
| Isopod, *Asellus bicrenata* | F, M | Cadmium chloride | 220 | 2,129[g] | - | **357.2** | 357.2 | Bosnak and Morgan 1981 |
| Isopod, *Lirceus alabamae* | F, M | Cadmium chloride | 152 | 150[g] | - | **39.29** | 39.29 | 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 | 39-48 | 68.3 | - | **81.91** | 81.91 | Spehar and Carlson 1984a,b |
| Amphipod, *Gammarus* sp. | S, U | - | 50 | 70 | - | 70.00 | - | Rehwoldt et al. 1973 |
| Crayfish (1.8 g), *Orconectes immunis* | F, M, T | Cadmium chloride | 44.4 | >10,200 | - | **>11,769** | >11,769 | Phipps and Holcombe 1985 |
| Crayfish, | S, M | Cadmium | - | 400 | - | - | - | Boutet and |

Table 1a. Continued

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | LC50 or EC50 (Total $\mu$g/L)[b] | LC50 or EC50 (Diss. $\mu$g/L) | LC50 or EC50 Adj. to Th=50 (Total $\mu$g/L) | Species Mean Acute Value at TH=50 (Total $\mu$g/L)[c] | Reference |
|---|---|---|---|---|---|---|---|---|
| Crayfish, *Orconectes virilis* | F, M, T | Cadmium chloride | 26 | 6,100 | - | **13,413** | 13,413 | Mirenda 1986 |
| Crayfish (juvenile), *Procambarus clarkii* | S, M | Cadmium chloride | 30 | 1,040 | - | **1,925** | 1,925 | 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 | - | **2,333** | 2,333 | Warnick and Bell 1969 |
| Damselfly, (Unidentified) | S, U | - | 50 | 8,100 | - | **8,100** | 8,100 | Rehwoldt et al. 1973 |
| Stonefly, *Pteronarcella badia* | F, M | Cadmium chloride | - | 18,000 | - | - | - | Clubb et al. 1975 |
| Caddisfly, (Unidentified) | S, U | - | 50 | 3,400 | - | **3,400** | 3,400 | Rehwoldt et al. 1973 |
| Midge, *Chironomus* sp. | S, U | - | 50 | 1,200 | - | 1,200 | - | Rehwoldt et al. 1973 |
| Midge (4th instar), *Chironomus riparius* | R, M, T | Cadmium chloride | 124 | 140,000 | - | 46,865 | - | Pascoe et al. 1990 |
| Midge (10-12 mm), *Chironomus riparius* | F, M, T | - | 152 | 300,000 | - | **78,579** | 78,579 | Williams et al. 1985 |
| Bryozoan, *Pectinatella magnifica* | S, U | - | 190-220 | 700 | - | **127.9** | 127.9 | Pardue and Wood 1980 |
| Bryozoan, *Lophopodella carteri* | S, U | - | 190-220 | 150 | - | **27.40** | 27.40 | Pardue and Wood 1980 |
| Bryozoan, *Plumatella emarginata* | S, U | - | 190-220 | 1,090 | - | **199.1** | 199.1 | Pardue and Wood 1980 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| American eel, *Anguilla rostrata* | S, M | - | 55 | 820 | - | **731.0** | 731.0 | Rehwoldt et al. 1973 |
| Coho salmon (1 year), *Oncorhynchus kisutch* | S, U | Cadmium chloride | 90 | 10.4 | - | 5.122 | - | Lorz et al. 1978 |
| Coho salmon (juvenile), *Oncorhynchus kisutch* | S, U | Cadmium chloride | 41 | 3.4 | - | 4.318 | - | Buhl and Hamilton 1991 |
| Coho salmon (adult), *Oncorhynchus kisutch* | F, M | Cadmium chloride | 23 | 17.5[d] | - | 44.60[d] | - | Chapman 1975 |
| Coho salmon (parr), *Oncorhynchus kisutch* | F, M | Cadmium chloride | 23 | 2.7 | - | **6.882** | 6.882 | Chapman 1975 |
| Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha* | S, U | Cadmium chloride | 211 | 26 | - | 4.587 | - | Hamilton and Buhl 1990 |
| Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha* | S, U | Cadmium chloride | 343 | 57 | - | 5.600 | - | Hamilton and Buhl 1990 |
| Chinook salmon (alevin), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 23 | >26[d] | - | >66.27[d] | - | Chapman 1975, 1978 |
| Chinook salmon (swim-up), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 23 | 1.8 | - | **4.588** | - | Chapman 1975, 1978 |
| Chinook salmon (parr), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 23 | 3.5 | - | **8.921** | - | Chapman 1975, 1978 |
| Chinook salmon | F, M | Cadmium | 23 | >2.9 | - | **>7.392** | - | Chapman 1975, 1978 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Chinook salmon (juvenile), *Oncorhynchus tshawytscha* | F, M | Cadmium chloride | 25 | 1.41 | - | **3.250** | - | Chapman 1982 |
| Chinook salmon (juvenile), *Oncorhynchus tshawytscha* | F, M | Cadmium sulfate | 20-22 | 1.1 | - | **3.129** | 4.984 | 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 | 39-48 | 2.3 | - | 2.720 | - | Spehar and Carlson 1984a,b |
| Rainbow trout (juvenile), *Oncorhynchus mykiss* | S, U | Cadmium chloride | 41 | 1.5 | - | 1.905 | - | Buhl and Hamilton 1991 |
| Rainbow trout (alevin), *Oncorhynchus mykiss* | F, M | Cadmium chloride | 23 | >27[d] | - | >68.82[d] | - | Chapman 1975, 1978 |
| Rainbow trout (swim-up), *Oncorhynchus mykiss* | F, M | Cadmium chloride | 23 | 1.3 | - | **3.314** | - | Chapman 1975, 1978 |
| Rainbow trout (parr), *Oncorhynchus mykiss* | F, M | Cadmium chloride | 23 | 1.0 | - | **2.549** | - | Chapman 1978 |
| Rainbow trout | F, M | Cadmium | 23 | 4.1 | - | **10.45** | - | Chapman 1975 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Rainbow trout (2 mo), *Oncorhynchus mykiss* | F, M | Cadmium nitrate | - | 6.6 | - | - | - | Hale 1977 |
| Rainbow trout, *Oncorhynchus mykiss* | F, M | Cadmium sulfate | 31 | 1.75 | - | **3.113** | - | Davies 1976 |
| Rainbow trout (8.8 g), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 44.4 | 3 | - | **3.462** | - | Phipps and Holcombe 1985 |
| Rainbow trout (fry), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 9.2 | <0.5 | - | **<3.844** | 4.296 | Cusimano et al. 1986 |
| Brown trout, *Salmo trutta* | S, M | Cadmium chloride | 39-48 | 1.4 | - | **1.656** | 1.656 | Spehar and Carlson 1984a,b |
| Brook trout, *Salvelinus fontinalis* | S, M | Cadmium sulfate | 42 | <1.5 | - | <1.851 | - | Carroll et al. 1979 |
| Brook trout, *Salvelinus fontinalis* | F, M | Cadmium chloride | 47.4 | 5,080 | - | 5,418 | -[i] | Holcombe et al. 1983 |
| Goldfish, *Carassius auratus* | S, U | Cadmium chloride | 20 | 2,340 | - | 7,058 | - | Pickering and Henderson 1966 |
| Goldfish, *Carassius auratus* | S, M | Cadmium chloride | 20 | 2,130 | - | 6,425 | - | McCarty et al. 1978 |
| Goldfish, *Carassius auratus* | S, M | Cadmium chloride | 140 | 46,800 | - | 13,535 | - | McCarty et al. 1978 |
| Goldfish (8.8 g), *Carassius auratus* | F, M, T | Cadmium chloride | 44.4 | 748 | - | **863.1** | 863.1 | Phipps and Holcombe 1985 |
| Common carp (yolk absorbed), *Cyprinus carpio* | R, U | Cadmium chloride | - | 140 | - | - | - | Ramesha et al. 1997 |
| Common carp | R, U | Cadmium | - | 2,840 | - | - | - | Ramesha et al. 1997 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| 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[d] | - | 1,865[d] | - | Suresh et al. 1993a |
| Common carp (fingerling), *Cyprinus carpio* | S, U | Cadmium nitrate | 100 | 17,100[d] | - | 7,418[d] | - | Suresh et al. 1993a |
| Common carp, *Cyprinus carpio* | S, M | - | 55 | 240 (at 28NC) | - | **214.0** | 214.0 | Rehwoldt et al. 1972 |
| Red shiner (0.8 - 2.0g) *Notropis lutrensis* | S, M, T | Cadmium sulfate | 85.5 | 6,620 | - | **3,468** | 3,468 | Carrier and Beitinger 1988a |
| Fathead minnow, *Pimephales promelas* | S, U | Cadmium chloride | 20 | 1,050[d] | - | 3,167[d] | - | Pickering and Henderson 1966 |
| Fathead minnow, *Pimephales promelas* | S, U | Cadmium chloride | 20 | 630[d] | - | 1,900[d] | - | Pickering and Henderson 1966 |
| Fathead minnow, *Pimephales promelas* | S, U | Cadmium chloride | 360 | 72,600[d] | - | 6,729[d] | - | Pickering and Henderson 1966 |
| Fathead minnow, *Pimephales promelas* | S, U | Cadmium chloride | 360 | 73,500[d] | - | 6,812[d] | - | Pickering and Henderson 1966 |
| Fathead minnow, *Pimephales promelas* | F, M | Cadmium sulfate | 201 | 11,200[d] | - | 2,095[d] | - | Pickering and Gast 1972 |
| Fathead minnow, *Pimephales promelas* | F, M | Cadmium sulfate | 201 | 12,000[d] | - | 2,245[d] | - | Pickering and Gast 1972 |
| Fathead minnow, *Pimephales promelas* | F, M | Cadmium sulfate | 201 | 6,400[d] | - | 1,197[d] | - | Pickering and Gast 1972 |
| Fathead minnow, | F, M | Cadmium | 201 | 2,000[d] | - | 374.1[d] | - | Pickering and Gast |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | F, M | Cadmium sulfate | 201 | 4,500[d] | - | 841.7[d] | - | Pickering and Gast 1972 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 40 | 21.5 | - | 28.13 | - | Spehar 1982 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 48 | 11.7 | - | 12.29 | - | Spehar 1982 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 39 | 19.3 | - | 26.04 | - | Spehar 1982 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 45 | 42.4 | - | 48.14 | - | Spehar 1982 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 47 | 54.2 | - | 58.40 | - | Spehar 1982 |
| Fathead minnow (fry), *Pimephales promelas* | S, M | Cadmium chloride | 44 | 29.0 | - | 33.83 | - | Spehar 1982 |
| Fathead minnow (adult), *Pimephales promelas* | S, M | Cadmium chloride | 103 | 3,060[d] | - | 1,281[d] | - | Birge et al. 1983 |
| Fathead minnow (adult), *Pimephales promelas* | S, M | Cadmium chloride | 103 | 2,900[d] | - | 1,214[d] | - | Birge et al. 1983 |
| Fathead minnow (adult), *Pimephales promelas* | S, M | Cadmium chloride | 103 | 3,100[d] | - | 1,298[d] | - | Birge et al. 1983 |
| Fathead minnow | S, M | Cadmium | 254-271 | 7,160[d] | - | 968.7[d] | - | Birge et al. 1983 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | S, M | Cadmium chloride | 39-48 | 1,280[d] | - | 1,493[d] | - | Spehar and Carlson 1984a,b |
| Fathead minnow (14-30 d), *Pimephales promelas* | S, U | Cadmium chloride | 120 | >150[h] | - | >52.24[h] | - | Hall et al. 1986 |
| Fathead minnow (0.8 - 2.0 g) *Pimephales promelas* | S, M, T | Cadmium sulfate | 85.5 | 3,580[d] | - | 1,876[d] | - | Carrier and Beitinger 1988a |
| Fathead minnow (<24 hr), *Pimephales promelas* | S, U | Cadmium nitrate | 60 | 210 | - | 168.6 | - | Rifici et al. 1996 |
| Fathead minnow (1-2 d), *Pimephales promelas* | S, U | Cadmium nitrate | 60 | 180 | - | 144.5 | - | Rifici et al. 1996 |
| Fathead minnow (<24 hr), *Pimephales promelas* | S, M, T | Cadmium nitrate | 280-300 | 73 (pH=6-6.5)<br>60 (pH=7-7.5)<br>65 (pH=8-8.8) | -<br>-<br>- | 8.780<br>7.216<br>7.817 | -<br>-<br>- | Schubauer-Berigan et al. 1993 |
| Fathead minnow (juvenile), *Pimephales promelas* | S, M, T | Cadmium chloride | 141 | 3,465[d] | 2,509 | 993.6[d] | - | Sherman et al. 1987 |
| Fathead minnow (0.6 g), *Pimephales promelas* | F, M, T | Cadmium chloride | 44.4 | 1,500[d] | - | 1,731[d] | - | Phipps and Holcombe 1985 |
| Fathead minnow (30 d), *Pimephales promelas* | F, M, T | Cadmium nitrate | 44 | 13.2 | - | **15.40** | 15.40 | Spehar and Fiandt 1986 |
| Colorado squawfish (larva), *Ptychocheilus lucius* | S, U | Cadmium chloride | 199 | 78 | - | **14.77** | - | Buhl 1997 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Colorado squawfish (juvenile), *Ptychocheilus lucius* | S, U | Cadmium chloride | 199 | 108 | - | **20.45** | 17.38 | Buhl 1997 |
| Northern pike minnow (juvenile), *Ptychocheilus oregonensis* | F, M | Cadmium chloride | 20-30 | 1,092 | - | **2,517** | - | Andros and Garton 1980 |
| Northern pike minnow (juvenile), *Ptychocheilus oregonensis* | F, M | Cadmium chloride | 20-30 | 1,104 | - | **2,545** | 2,531 | Andros and Garton 1980 |
| Bonytail (larva), *Gila elegans* | S, U | Cadmium chloride | 199 | 148 | - | **28.02** | - | Buhl 1997 |
| Bonytail (juvenile), *Gila elegans* | S, U | Cadmium chloride | 199 | 168 | - | **31.81** | 29.85 | Buhl 1997 |
| White sucker, *Catostomus commersoni* | F, M | Cadmium chloride | 18 | 1,110 | - | **3,801** | 3,801 | Duncan and Klaverkamp 1983 |
| Razorback sucker (larva), *Xyrauchen texanus* | S, U | Cadmium chloride | 199 | 139 | - | **26.32** | - | Buhl 1997 |
| Razorback sucker (juvenile), *Xyrauchen texanus* | S, U | Cadmium chloride | 199 | 160 | - | **30.29** | 28.23 | Buhl 1997 |
| Channel catfish (7.4 g), *Ictalurus punctatus* | F, M, T | Cadmium chloride | 44.4 | 4,480 | - | **5,169** | 5,169 | Phipps and Holcombe 1985 |
| Banded killifish, *Fundulus diaphanus* | S, M | - | 55 | 110 | - | **98.07** | 98.07 | Rehwoldt et al. 1972 |
| Flagfish, *Jordanella floridae* | F, M | Cadmium chloride | 44 | 2,500 | - | **2,916** | 2,916 | Spehar 1976a,b |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|
| Mosquitofish, *Gambusia affinis* | F, M | Cadmium chloride | 11.1 | 900 | - | **5,519** | - | Giesy et al. 1977 |
| Mosquitofish, *Gambusia affinis* | F, M | Cadmium chloride | 11.1 | 2,200 | - | **13,490** | 8,628 | Giesy et al. 1977 |
| Guppy, *Poecilia reticulata* | S, U | Cadmium chloride | 20 | 1,270 | - | **3,831** | 3,831 | Pickering and Henderson 1966 |
| Threespine stickleback, *Gasterosteus aculeatus* | S, U | Cadmium chloride | 115 | 6,500 | - | **2,383** | - | Pascoe and Cram 1977 |
| Threespine stickleback, *Gasterosteus aculeatus* | R, M | Cadmium chloride | 103-111 | 23,000 | - | **9,196** | 4,681 | Pascoe and Mattey 1977 |
| White perch, *Morone americana* | S, M | - | 55 | 8,400 | - | **7,489** | 7,489 | Rehwoldt et al. 1972 |
| Striped bass, *Morone saxatilis* | S, M | - | 55 | 1,100 | - | 980.7[e] | - | Rehwoldt et al. 1972 |
| Striped bass (larva), *Morone saxatilis* | S, U | Cadmium chloride | 34.5 | 1 | - | 1.564[e] | - | Hughes 1973 |
| Striped bass (fingerling), *Morone saxatilis* | S, U | Cadmium chloride | 34.5 | 2 | - | 3.128[e] | - | Hughes 1973 |
| Striped bass (63 d), *Morone saxatilis* | S, U | Cadmium chloride | 40 | 4 | - | **5.234** | - | Palawski et al. 1985 |
| Striped bass (63 d), *Morone saxatilis* | S, U | Cadmium chloride | 285 | 10 | - | **1.228** | 2.535 | Palawski et al. 1985 |
| Green sunfish, *Lepomis cyanellus* | S, U | Cadmium chloride | 20 | 2,840 | - | 8,566 | - | Pickering and Henderson 1966 |
| Green sunfish, *Lepomis cyanellus* | S, U | Cadmium chloride | 360 | 66,000 | - | 6,117 | - | Pickering and Henderson 1966 |

Table 1. 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 |
|---|---|---|---|---|---|---|---|---|
| Green sunfish (juvenile), *Lepomis cyanellus* | S, M, T | Cadmium sulfate | 85.5 | 11,520 | - | 6,036 | - | Carrier and Beitinger 1988b |
| Green sunfish, *Lepomis cyanellus* | F, M | Cadmium chloride | 335 | 20,500 | - | **2,072** | 2,072 | Jude 1973 |
| Pumpkinseed, *Lepomis gibbosus* | S, M | - | 55 | 1,500 | - | **1,337** | 1,337 | Rehwoldt et al. 1972 |
| Bluegill, *Lepomis macrochirus* | S, U | Cadmium chloride | 20 | 1,940 | - | 5,852 | - | Pickering and Henderson 1966 |
| Bluegill, *Lepomis macrochirus* | S, M | Cadmium chloride | 18 | 3,860 | - | 13,219 | - | Bishop and McIntosh 1981 |
| Bluegill, *Lepomis macrochirus* | S, M | Cadmium chloride | 18 | 2,800 | - | 9,589 | - | Bishop and McIntosh 1981 |
| Bluegill, *Lepomis macrochirus* | S, M | Cadmium chloride | 18 | 2,260 | - | 7,740 | - | Bishop and McIntosh 1981 |
| Bluegill, *Lepomis macrochirus* | F, M | Cadmium chloride | 207 | 21,100 | - | **3,809** | - | Eaton 1980 |
| Bluegill (1.0 g), *Lepomis macrochirus* | F, M, T | Cadmium chloride | 44.4 | 6,470 | - | **7,466** | 5,333 | Phipps and Holcombe 1985 |
| Tilapia *Oreochromis mossambica* | R, U | Cadmium chloride | 28.4 | 6,000[d] | - | **11,861** | 11,861 | Gaikwad 1989 |
| African clawed frog, *Xenopus laevis* | R, U | Cadmium chloride | 112-120 | 3,597 | - | **1,305** | 1,305 | Sunderman et al. 1991 |
| Salamander (3 mo larva), *Ambystoma gracile* | F, M, T | Cadmium chloride | 45 | 468.4 | - | **531.8** | 531.8 | Nebeker et al. 1995 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|---|

Table 1a. 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) | 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[d] | - | - | Reish et al. 1976 |
| Polychaete worm, *Capitella capitata* | S, U | Cadmium chloride | - | 2,800[d] | - | - | 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. 1982a |
| Oligochaete worm, *Monopylephorus cuticulatus* | R, U | Cadmium sulfate | - | **135,000** | - | 135,000 | Chapman et al. 1982a |
| Oligochaete worm, *Tubificoides gabriellae* | R, U | Cadmium sulfate | - | **24,000** | - | 24,000 | Chapman et al. 1982a |
| Oyster drill, | S, U | Cadmium | - | **6,600** | - | 6,600 | Eisler 1971 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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[d] | - | - | Eisler 1971 |
| Blue mussel, *Mytilus edulis* | S, M | Cadmium chloride | - | 1,620[d] | - | - | Ahsanullah 1976 |
| Blue mussel, *Mytilus edulis* | F, M | Cadmium chloride | - | 3,600[d] | - | - | Ahsanullah 1976 |
| Blue mussel, *Mytilus edulis* | F, M | Cadmium chloride | - | 4,300[d] | - | - | Ahsanullah 1976 |
| Blue mussel (embryo), *Mytilus edulis* | S, U | Cadmium chloride | - | **1,200** | - | - | Martin et al. 1981 |
| Blue Mussel (juvenile), *Mytilus edulis* | R, U | Cadmium chloride | 2.5 | **960** | - | 1,073 | Nelson et al. 1988 |
| Bay scallop (juvenile), *Argopecten irradians* | S, U | Cadmium chloride | - | **1,480** | - | 1,480 | Nelson et al. 1976 |
| Pacific oyster (embryo), *Crassostrea gigas* | S, U | Cadmium chloride | - | **611** | - | - | Martin et al. 1981 |
| Pacific oyster (larva), *Crassostrea gigas* | S, U | Cadmium chloride | - | **85** | - | 227.9 | Watling 1982 |
| Eastern oyster (larva), *Crassostrea virginica* | S, U | Cadmium chloride | - | **3,800** | - | 3,800 | Calabrese et al. 1973 |
| Soft-shell clam, *Mya arenaria* | S, U | Cadmium chloride | - | **2,200** | - | - | Eisler 1971 |
| Soft-shell clam, *Mya arenaria* | S, U | Cadmium chloride | - | **2,500** | - | - | Eisler and Hennekey 1977 |
| Soft-shell clam, *Mya arenaria* | S, U | Cadmium chloride | - | **850** | - | 1,672 | Eisler 1977 |
| Squid (larva), *Loligo opalescens* | S, M, T | Cadmium chloride | 30 | **>10,200** | - | >10,200 | Dinnel et al. 1989 |
| Copepod, *Pseudodiaptomus coronatus* | S, U | Cadmium chloride | - | **1,708** | - | 1,708 | Gentile 1982 |
| Copepod, *Eurytemora affinis* | S, U | Cadmium chloride | - | 1,080[d] | - | - | Gentile 1982 |
| Copepod (naupilus), *Eurytemora affinis* | S, U | Cadmium chloride | - | **147.7** | - | 147.7 | Sullivan et al. 1983 |
| Copepod, | S, U | Cadmium | - | **144** | - | 144 | Gentile 1982 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| 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 1a. 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 |
|---|---|---|---|---|---|---|---|
| Mysid (7 d), *Americamysis bahia* | S, M, T, D | Cadmium chloride | 6 | 14.7 | 2.8 | - | DeLisle and Roberts 1988 |
| Mysid (7 d), *Americamysis bahia* | S, M, T, D | Cadmium chloride | 14 | 38.0 | 3.6 | - | DeLisle and Roberts 1988 |
| Mysid (7 d), *Americamysis bahia* | S, M, T, D | Cadmium chloride | 22 | 70.4 | 4.1 | - | DeLisle and Roberts 1988 |
| Mysid (7 d), *Americamysis bahia* | S, M, T, D | Cadmium chloride | 30 | 77.3 | 2.9 | - | DeLisle and Roberts 1988 |
| Mysid (7 d), *Americamysis bahia* | S, M, T, D | Cadmium chloride | 38 | 90.3 | 2.3 | - | DeLisle 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 | 15-23 | **15.5** | - | - | Nimmo et al. 1977a |
| Mysid, *Americamysis bahia* | F, M | Cadmium chloride | 30 | **110** | - | 41.29 | Gentile et al. 1982; Lussier et al. Manuscript |
| 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, *Ampelisca abdita* | S, M, T | Cadmium chloride | 28 | 400 | - | - | Redmond et al. 1994 |
| 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[d] | - | - | Wright and Frain 1981 |
| Amphipod (young), *Marinogammarus obtusatus* | S, M | Cadmium chloride | - | **3,500** | - | 3,500 | Wright and Frain 1981 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| 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[f]<br>17,500[f]<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[d] | - | - | Nimmo et al. 1977b |
| Pink shrimp (2nd post larva), *Penaeus duorarum* | S, U | cadmium chloride | 25 | **310.5** | - | 310.5 | Cripe 1994 |
| Grass shrimp (adult), *Palaemonetes pugio* | S, U | Cadmium chloride | 20 | **1,830** (Big Sheepshead Creek) | - | - | Khan et al. 1988 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| 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** | - | 7,384 | Frank and Robertson 1979 |
| Green crab, *Carcinus maenas* | S, U | Cadmium chloride | - | **4,100** | - | 4,100 | Eisler 1971 |
| Fiddler crab, *Uca pugilator* | S, U | Cadmium chloride | 20 | **46,600** | - | - | O'Hara 1973a |
| 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, | S, U | Cadmium | - | **23,300** | - | - | O'Hara 1973a |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| Fiddler crab, *Uca pugilator* | S, U | Cadmium chloride | - | **10,400** | - | - | O'Hara 1973a |
| Fiddler crab, *Uca pugilator* | S, U | Cadmium chloride | - | **6,800** | - | 21,238 | O'Hara 1973a |
| Starfish, *Asterias forbesi* | S, U | Cadmium chloride | - | **820** | - | - | Eisler 1971 |
| Starfish, *Asterias forbesi* | S, U | Cadmium chloride | - | **7,100** | - | 2,413 | Eisler and Hennekey 1977 |
| Green sea urchin (embryo), *Strongylocentrotus droebachiensis* | S, M, T | Cadmium chloride | 30 | **1,800** | - | 1,800 | Dinnel et al. 1989 |
| Purple sea urchin (embryo), *Strongylocentrotus purpuratus* | S, M, T | Cadmium chloride | 30 | **500** | - | 500 | Dinnel et al. 1989 |
| Sand dollar (embryo), *Dendraster excentricus* | S, M, T | Cadmium chloride | 30 | **7,400** | - | 7,400 | Dinnel et al. 1989 |
| Coho salmon (smolt), *Oncorhynchus kisutch* | F, M, T | Cadmium chloride | 28.3 | **1,500** | - | 1,500 | Dinnel et al. 1989 |
| Sheepshead minnow, *Cyprinodon variegatus* | S, U | Cadmium chloride | - | **50,000** | - | 50,000 | Eisler 1971 |
| Mummichog (adult), *Fundulus heteroclitus* | S, U | Cadmium chloride | - | 49,000 | - | - | Eisler 1971 |
| Mummichog (juvenile), *Fundulus heteroclitus* | S, U | Cadmium chloride | 20 | 114,000 | - | - | Voyer 1975 |
| Mummichog (juvenile), *Fundulus heteroclitus* | S, U | Cadmium chloride | 20 | 92,000 | - | - | Voyer 1975 |
| Mummichog (juvenile), *Fundulus heteroclitus* | S, U | Cadmium chloride | 20 | 78,000 | - | - | Voyer 1975 |
| Mummichog (juvenile), *Fundulus heteroclitus* | S, U | Cadmium chloride | 10 | 73,000 | - | - | Voyer 1975 |
| 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), | S, U | Cadmium | 32 | 30,000 | - | - | Voyer 1975 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| 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[d] | - | - | Park et al 1994 |
| Rivulus (120 d adult), *Rivulus marmoratus* | S, M, T | Cadmium chloride | 10 | 32,200[d] | - | - | Park et al 1994 |
| Rivulus (11-18 mm), *Rivulus marmoratus* | F, M, T | Cadmium sulfate | 14 | 21,100[d] | - | - | 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[d] | - | - | Cardin 1982 |
| Atlantic silverside (juvenile), *Menidia menidia* | S, U | Cadmium chloride | - | 28,532[d] | - | - | Cardin 1982 |
| Atlantic silverside (juvenile), *Menidia menidia* | S, U | Cadmium chloride | - | 13,652[d] | - | - | Cardin 1982 |
| Atlantic silverside (larva), *Menidia menidia* | S, U | Cadmium chloride | - | **1,054** | - | - | Cardin 1982 |
| Atlantic silverside (larva), *Menidia menidia* | S, U | Cadmium chloride | - | **577** | - | 779.8 | Cardin 1982 |
| 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 | F, M, T | Cadmium | 30.1 | **11,000** | - | 11,000 | Dinnel et al. 1989 |

Table 1a. 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 |
|---|---|---|---|---|---|---|---|
| Striped mullet (50 mm juvenile), *Mugil cephalus* | S, U | Cadmium chloride | 37.3 | 28,000[d] | - | - | 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[j] | - | - | 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 measur
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 sp values presented may be different than those calculated with a hand held calculator due to rounding. Each SMAV was calculated from t 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.
i No Species Mean Acute Value calculated because acute values are too divergent for this species.
j Not used in calculations because this lower value was obtained in artificial sea water.

Table 1b. Results of Covariance Analysis of Freshwater Acute Toxicity versus Hardness

Results of Covariance Analysis of Freshwater Acute Toxicity versus Hardness

| Species | n | Slope | 95% Confidence Limits | Error Degrees of Freedom |
|---|---|---|---|---|
| *Limnodrilus hoffmeisteri* | 2 | 0.7888 | cannot calculate | 0 |
| *Ceriodaphnia reticulata* | 3 | 0.6064 | 0.3422, 0.8706 | 1 |
| *Daphnia magna* (all data) | 29 | 0.1720 | -0.5658, 0.9099 | 27 |
| *Daphnia magna* (Chapman et al. Manuscript) | 5 | 1.1824* | 0.6042, 1.7606 | 3 |
| *Daphnia pulex* | 6 | 0.9447* | 0.3499, 1.5395 | 4 |
| Goldfish | 4 | 1.4608 | -1.3925, 4.3141 | 2 |
| Fathead minnow | 29 | 1.5351* | 0.5523, 2.5179 | 27 |
| Green sunfish | 4 | 0.8986 | 0.1508, 1.6464 | 2 |
| Bluegill | 6 | 0.8647* | 0.5199, 1.2095 | 4 |
| Chinook salmon | 6 | 1.2576* | 0.8766, 1.6386 | 4 |
| Striped bass | 4 | 0.8089 | -0.3206, 1.9384 | 2 |
| All of above using all data for *D. magna* | 93 | 0.9931*@ | 0.6301, 1.3561 | 82 |
| All of above except using only data from Chapman et al. (Manuscript) for *D. magna* | 69 | 1.2049*# | 0.8078, 1.6021 | 58 |

* Slope is significantly different than 0 ($p<0.05$).
@ Individual slopes not significantly different ($p=0.66$).
\# Individual slopes not significantly different ($p=0.99$).

Table 2a. Chronic Toxicity of Cadmium to Aquatic 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) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FRESHWATER SPECIES | | | | | |
| Oligochaete, *Aeolosoma headleyi* | LC | - | 65 | - | - | 25.19 | - | 19.42 | 19.42 | Niederleher 1984 |
| Snail, *Aplexa hypnorum* | LC | Cadmium chloride | 45.3 | 4.41-7.63 | - | 5.801 | - | 6.398 | - | Holcombe et al. 1984 |
| Snail, *Aplexa hypnorum* | LC | Cadmium chloride | 45.3 | 2.50-4.79 | - | 3.460 | - | 3.816 | 4.941 | Holcombe et al. 1984 |
| Cladoceran, *Ceriodaphnia dubia* | LC | - | 20 | 10-19 | - | 13.78 | - | 34.19 | 34.19 | Jop et al. 1995 |
| Cladoceran, *Daphnia magna* | LC | Cadmium chloride | 53 | 0.08-0.29 | - | 0.1523 | - | 0.1437 | - | Chapman et al. Manuscript |
| Cladoceran, *Daphnia magna* | LC | cadmium chloride | 103 | 0.16-0.28 | - | 0.2117 | - | 0.1034 | - | Chapman et al. Manuscript |
| Cladoceran, *Daphnia magna* | LC | Cadmium chloride | 209 | 0.21-0.91 | - | 0.4371 | - | 0.1058 | - | Chapman et al. Manuscript |

Table 2a. 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) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Daphnia magna* | LC | Cadmium chloride | 150 | 0.5-1.0 | - | 0.7071 | - | 0.2379 | - | Bodar et al. 1988b |
| Cladoceran, *Daphnia magna* | LC | Cadmium chloride | 130 | <1.86-1.86 | - | <1.86 | - | <0.7211 | 0.1933 | Borgmann et al. 1989 |
| Cladoceran, *Daphnia pulex* | LC | - | 65 | - | - | 7.49 | - | 5.774 | 5.774 | Niederlehner 1984 |
| Amphipod, *Hyalella azteca* | LC | Cadmium chloride | 280 | 0.5-2.0 | - | 1.000 | - | 0.1811 | 0.1811 | Ingersoll and Kemble Manuscript |
| Midge, *Chironomus tentans* | LC | Cadmium chloride | 280 | 5.8-16.4 | - | 9.753 | - | 1.767 | 1.767 | Ingersoll and Kemble Manuscript |
| Coho salmon (Lake Supr.), *Oncorhynchus kisutch* | ELS | Cadmium chloride | 44 | 1.3-3.4 | - | 2.102 | - | 2.386 | - | Eaton et al. 1978 |

Table 2a. 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) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Coho salmon (West Coast), *Oncorhynchus kisutch* | ELS | Cadmium chloride | 44 | 4.1-12.5 | - | 7.159 | - | 8.127 | 4.404 | Eaton et al. 1978 |
| Chinook salmon, *Oncorhynchus tshawytscha* | ELS | Cadmium chloride | 25 | 1.3-1.88 | - | 1.563 | - | 3.108 | 3.108 | Chapman 1975 |
| Rainbow trout (270 d), *Oncorhynchus mykiss* | LC | Cadmium sulfate | 250 | 3.39-5.48 | - | 4.310 | - | 0.8736 | 0.8736 | Brown et al. 1994 |
| Atlantic salmon, *Salmo salar* | ELS | Cadmium chloride | 19-28 | 90-270 (5NC) | - | 155.9[c] | - | 329.6[d] | - | Rombough and Garside 1982 |
| | | | | 2.5-8.2 (9.6NC) | - | 4.528 | - | 9.574 | 9.574 | |
| Brown trout, *Salmo trutta* | ELS | Cadmium chloride | 44 | 3.8-11.7 | - | 6.668 | - | 7.569 | - | Eaton et al. 1978 |
| Brown trout, *Salmo trutta* | LC | Cadmium sulfate | 250 | 9.34-29.1 | - | 16.49 | - | 3.342 | 5.029 | Brown et al. 1994 |

Table 2a. 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) | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| Brook trout, *Salvelinus fontinalis* | LC | Cadmium chloride | 44 | 1.7-3.4 | - | 2.404 | - | 2.729 | - | Benoit et al. 1976 |
| Brook trout, *Salvelinus fontinalis* | ELS | Cadmium chloride | 37 | 1-3 | - | 1.732 | - | 2.335 | - | Sauter et al. 1976 |
| Brook trout, *Salvelinus fontinalis* | ELS | Cadmium chloride | 44 | 1.1-3.8 | - | 2.045 | - | 2.321 | 2.455 | Eaton et al. 1978 |
| Lake trout, *Salvelinus namaycush* | ELS | Cadmium chloride | 44 | 4.4-12.3 | - | 7.357 | - | 8.351 | 8.351 | Eaton et al. 1978 |
| Northern pike, *Esox lucius* | ELS | Cadmium chloride | 44 | 4.2-12.9 | - | 7.361 | - | 8.356 | 8.356 | Eaton et al. 1978 |
| Fathead minnow, *Pimephales promelas* | LC | Cadmium sulfate | 201 | 37-57 | - | 45.92 | - | 11.56 | - | Pickering and Gast 1972 |
| Fathead minnow, *Pimephales promelas* | ELS | Cadmium nitrate | 44 | - | - | 10.0 | - | 11.35 | 11.45 | Spehar and Fiandt 1986 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| White sucker, *Catostomus commersoni* | ELS | Cadmium chloride | 44 | 4.2-12.0 | - | 7.099 | - | 8.059 | 8.059 | Eaton et al. 1978 |
| Flagfish, *Jordanella floridae* | LC | Cadmium chloride | 44 | 4.1-8.1 | - | 5.763 | - | 6.542 | - | Spehar 1976a |
| Flagfish, *Jordanella floridae* | LC | Cadmium chloride | 44-51 | 3.0-6.5 | - | 4.416 | - | 4.646 | - | Carlson et al. 1982 |
| Flagfish, *Jordanella floridae* | LC | Cadmium chloride | 44-51 | 3.4-7.3 | - | 4.982 | - | 5.242 | 5.421 | Carlson et al. 1982 |
| Bluegill, *Lepomis macrochirus* | LC | Cadmium sulfate | 207 | 31-80 | - | 49.80 | - | 12.17 | - | Eaton 1974 |
| Bluegill, *Lepomis macrochirus* | LC | Cadmium chloride | 134 | NOEC >32.3 | - | >32.3 | - | >12.15 | 12.16 | Cope et al. 1994 |
| Smallmouth bass, *Micropterus dolomieui* | ELS | Cadmium chloride | 44 | 4.3-12.7 | - | 7.390 | - | 8.389 | 8.389 | Eaton et al. 1978 |
| Blue tilapia, *Oreochromis aurea* | LC | Cadmium nitrate | 145 | >52 | - | >52 | - | >18.09 | >18.09 | Papoutsoglou and Abel 1988 |

Table 2a. Continued

| 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) | 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. Manuscript |
| 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] Not used in calculations (see text).

Table 2b. Results of Covariance Analysis of Freshwater Chronic Toxicity versus Hardness

Results of Covariance Analysis of Freshwater Chronic Toxicity versus Hardness

| Species | n | Slope | 95% Confidence Limits | Degrees of Freedom |
|---|---|---|---|---|
| *Daphnia magna* (Chapman et al. Manuscript) | 4 | 0.9786 | -0.5044, 2.4615 | 3 |
| Fathead minnow | 2 | 1.0034 | Cannot be calculated | 1 |
| All species | 6* | 0.9917 | 0.3179, 1.6654 | 5 |

* Slope is significantly different from 0 (p=0.05).

Table 2c. Acute-Chronic Ratio

## Acute-Chronic Ratio

### Freshwater Species

| Species | Reference | Hardness (mg/L as $CaCO_3$) | Acute Value ($\mu$g/L) | Chronic Value ($\mu$g/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 |

| Species | Reference | Hardness (mg/L as $CaCO_3$) | Acute Value (µg/L) | Chronic Value (µg/L) | Ratio | Species Mean Acute-Chronic Ratio |
|---|---|---|---|---|---|---|
| | | **Saltwater Species** | | | | |
| Mysid, *Americamysis bahia* | Nimmo et al. 1977a | - | 15.5 | 8.237 | 1.882 | - |
| Mysid, *Americamysis bahia* | Gentile et al. 1982 | - | 110 | 7.141 | 15.40 | 5.384 |
| Mysid, *Mysidopsis bigelowi* | Gentile et al. 1982 | - | 110 | 7.141 | 15.40 | 15.40 |

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

Table 3a. Ranked 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 | | |
| 59 | 78,579 | Midge, *Chironomus riparius* | 78,579 | - |
| 58 | 12,673 | Planarian, *Dendrocoelum lacteum* | 12,673 | - |
| 57 | >12,564 | Crayfish, *Orconectes virilis* | 13,413 | - |
| | | Crayfish, *Orconectes immunis* | >11,769 | - |
| 56 | 11,861 | Tilapia, *Oreochromis mossambica* | 11,861 | - |
| 55 | 9,413 | Tubificid worm, *Rhyacodrilus montana* | 9,413 | - |
| 54 | 8,628 | Mosquitofish, *Gambusia affinis* | 8,628 | - |

| | | | | |
|---|---|---|---|---|
| 53 | 8,218 | Tubificid worm, *Stylodrilus heringianus* | 8,218 | - |
| 52 | 8,100 | Damselfly, Unidentified. | 8,100 | - |
| 51 | 5,930 | Tubificid worm, *Spirosperma ferox* | 5,230 | - |
| | | Tubificid worm, *Spirosperma nikolskyi* | 6,724 | - |
| 50 | 5,678 | Tubificid worm, *Varichaeta pacifica* | 5,678 | - |
| 49 | 5,169 | Channel catfish, *Ictalurus punctatus* | 5,169 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 48 | 4,781 | Tubificid worm, *Quistradilus multisetosus* | 4,781 | - |
| 47 | 4,781 | Tubificid worm, *Tubifex tubifex* | 4,781 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 46 | 4,681 | Threespine stickleback, *Gasterosteus aculeatus* | 4,681 | - |
| 45 | 3,831 | Guppy, *Poecilia reticulata* | 3,831 | - |
| 44 | 3,801 | White sucker, *Catostomus commersoni* | 3,801 | - |
| 43 | 3,586 | Tubificid worm, *Branchiura sowerbyi* | 3,586 | - |
| 42 | 3,468 | Red shiner, *Notropis lutrenis* | 3,468 | - |
| 41 | 3,400 | Caddisfly, (Unidentified) | 3,400 | - |
| 40 | 2,916 | Flagfish, *Jordanella floridae* | 2,916 | 433.8 |
| 39 | 2,454 | Green sunfish, *Lepomis cyanellus* | 2,072 | - |

Table 3a. (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 |
|---|---|---|---|---|
| | | Pumpkinseed, *Lepomis gibbosus* | 1,337 | - |
| | | Bluegill, *Lepomis macrochirus* | 5,333 | 423.7 |
| 38 | 2,333 | Mayfly, *Ephemerella grandis* | 2,333 | - |
| 37 | 1,925 | Crayfish, *Procambarus clarkii* | 1,925 | - |
| 36 | 1,700 | Amphipod, *Crangonyx pseudogracilis* | 1,700 | - |
| 35 | 1,700 | Worm, *Nais sp.* | 1,700 | - |
| 34 | 1,305 | African clawed frog, *Xenopus laevis* | 1,305 | - |
| 33 | 863.1 | Goldfish, *Carassius auratus* | 863.1 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 32 | 731.0 | American eel, *Anguilla rostrata* | 731.0 | - |
| 31 | 628.6 | Tubificid worm, *Limnodrilus hoffmeisteri* | 628.6 | - |
| 30 | 531.8 | Salamander, *Ambystoma gracile* | 531.8 | - |
| 29 | 357.2 | Isopod, *Asellus bicrenata* | 357.2 | - |
| 28 | 214.0 | Common carp, *Cyprinus carpio* | 214.0 | - |
| 27 | 213.5 | Cladoceran, *Alona affinis* | 213.5 | - |
| 26 | 199.1 | Bryozoan, *Plumatella emarginata* | 199.1 | - |
| 25 | 192.8 | Copepod, *Cyclops varicans* | 192.8 | - |
| 24 | 162.6 | Leech, *Glossiponia complanta* | 162.6 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 23 | 127.9 | Bryozoan, *Pectinatella magnifica* | 127.9 | - |
| 22 | 106.0 | Snail, *Aplexa hypnorum* | 106.0 | 20.76[c] |
| 21 | 98.07 | Banded killifish, *Fundulus diaphanus* | 98.07 | - |
| 20 | 93.81 | Worm, *Lumbriculus variegatus* | 93.81 | - |
| 19 | 81.91 | Amphipod, *Gammarus pseudolimnaeus* | 81.91 | - |
| 18 | 77.15 | Snail, *Physa gyrina* | 77.15 | - |
| 17 | 39.29 | Isopod, *Lirceus alabamae* | 39.29 | - |
| 16 | 39.26 | Cladoceran, *Moina macrocopa* | 39.26 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 15 | 35.41 | Mussel, *Lampsilis straminea claibornensis* | 38.00 | - |
| | | Mussel, *Lampsilis teres* | 33.00 | - |
| 14 | 34.90 | Cladoceran, *Ceriodaphnia dubia* | 28.29 | - |
| | | Cladoceran, *Ceriodaphnia reticulata* | 43.05 | - |
| 13 | 31.04 | Cladoceran, *Simocephalus serrulatus* | 35.36 | - |
| | | Cladoceran, *Simocephalus vetulus* | 27.25 | - |
| 12 | 30.73 | Mussel, *Actinonaia pectorosa* | 30.73 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 11 | 30.50 | Mussel, *Utterbackia imbecilis* | 30.50 | - |
| 10 | 29.85 | Bonytail, *Gila elegans* | 29.85 | - |
| 9 | 29.71 | Cladoceran, *Daphnia magna* | 18.34 | 104.3[d] |
| | | Cladoceran, *Daphnia pulex* | 48.12 | - |
| 8 | 28.23 | Razorback sucker, *Xyrauchen texanus* | 28.23 | - |
| 7 | 27.40 | Bryozoan, *Lophopodella carteri* | 27.40 | - |
| 6 | 17.38 | Colorado squawfish, *Ptychocheilus lucius* | 17.38 | - |
| | | Northern pike minnow *Ptychocheilus oregonensis* | 2,531[f] | - |

Table 3a. (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 |
|---|---|---|---|---|
| 5 | 15.40 | Fathead minnow, *Pimephales promelas* | 15.40 | 13.13[c] |
| 4 | 12.00 | Mussel, *Anodonta coupierana* | 12.00 | - |
| 3 | 5.282 | Coho salmon, *Oncorhynchus kisutch* | 6.882 | - |
| | | Chinook salmon, *Oncorhynchus tshawytscha* | 4.984 | 0.9021 |
| | | Rainbow trout, *Oncorhynchus mykiss* | 4.296 | - |
| 2 | 2.535 | White perch, *Morone americana* | 7,489[e] | - |
| | | Striped bass, *Morone saxatilis* | 2.535 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 1 | 1.656 | Brown trout, *Salmo trutta* | 1.656 | - |
| | | 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 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 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 | - |
| 44 | >10,200 | Squid, *Loligo opalescens* | >10,200 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 43 | 10,000 | Oligochaete worm, *Limnodriloides verrucosus* | 10,000 | - |
| 42 | 7,400 | Sand dollar, *Dendraster excentricus* | 7,400 | - |
| 41 | 7,384 | Blue crab, *Callinectes sapidus* | 7,384 | - |
| 40 | 7,120 | Isopod, *Limnoria tripunctata* | 7,120 | - |
| 39 | 7,079 | Striped mullet, *Mugil cephalus* | 7,079 | - |
| 38 | 6,895 | Polychaeta worm, *Nereis grubei* | 4,700 | - |
| | | Sand worm, *Nereis virens* | 10,114 | - |
| 37 | 6,700 | Amphipod, *Diporeia spp.* | 6,700 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 36 | 6,600 | Oyster drill, *Urosalpinx cinerea* | 6,600 | - |
| 35 | 4,100 | Green crab, *Carcinus maenas* | 4,100 | - |
| 34 | 3,500 | Amphipod, *Marinogammarus obtusatus* | 3,500 | - |
| 33 | 2,900 | Amphipod, *Ampelisca abdita* | 2,900 | - |
| 32 | 2,600 | Polychaete worm, *Pectinaria californiensis* | 2,600 | - |
| 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 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 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 | - |
| 23 | 948.7 | Green sea urchin, *Strongylocentrotus droebachiensis* | 1,800 | - |

Table 3a. (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 |
|---|---|---|---|---|
| | | 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 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 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 | - |
| 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 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 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 |
| 3 | 78 | American lobster, *Homarus americanus* | 78 | - |
| 2 | 75.0 | Striped bass, *Morone saxatilis* | 75.0 | - |

Table 3a. (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 |
|---|---|---|---|---|
| 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 2C.
[d] Geometric mean of three values in Table 2C.
[e] Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3. (continued)

**Fresh water**

CMC:

Final Acute Value = 5.995 $\mu$g/L (calculated at a hardness of 50 mg/L from Genus Mean Acute Values).

Final Acute Value = 4.296 $\mu$g/L (lowered to protect rainbow trout at a hardness of 50 mg/L; see text)

Criterion Maximum Concentration = (4.296 $\mu$g/L) /2 = 2.148 $\mu$g/L Total Cadmium (at a hardness of 50 mg/L)

Pooled Slope = 1.205 (see Table 1)

1n (Criterion Maximum Intercept) = 1n(2.148) - [slope x 1n(50)]

= 0.7645 - (1.205 x 3.912) = -3.949

Criterion Maximum Concentration for Total Cadmium (at a hardness of 50 mg/L) = $e^{(1.205[\ln(\text{hardness})]-3.949)}$

Criterion Maximum Concentration for Dissolved Cadmium (at 50 mg/L hardness) = 0.97 [$e^{(1.205[1n(\text{hardness})]-3.949)}$]

CCC:

Total Cadmium Freshwater Final Chronic Value = 0.0861 $\mu$g/L (see text)

Slope = 0.9917 (see text)

1n (Final Chronic intercept) = 1n (0.0861) - [slope x 1n(50)]

$= -2.452 - (0.9917 \times 3.912) = -6.332$

Total Cadmium Freshwater Final Chronic Value (at a hardness of 50 mg/L) = $e^{(0.9917 [1n(hardness)]-6.332)}$

Dissolved Cadmium Freshwater Final Chronic Value (at 50 mg/L hardness) = 0.94 $[e^{(0.9 [1n(hardness)]-6.332)}]$

**Salt water**

CMC:

Total Cadmium Final Acute Value = 80.55 $\mu$g/L

Total Cadmium Criterion Maximum Concentration = (80.55 $\mu$g/L)/2 = 40.28 $\mu$g/L

Dissolved Cadmium Criterion Maximum Concentration = 0.994 (40.28 $\mu$g/L) = 40.04 $\mu$g/L

Final Acute-Chronic Ratio = 9.106 (see text)

CCC:

Total Cadmium Final Chronic Value = (80.55 $\mu$g/L)/9.106 = 8.846 $\mu$g/L

Dissolved Cadmium Final Chronic Value = 0.994 (8.846 $\mu$g/L) = 8.793 $\mu$g/L

Table 3b. Ranked Freshwater Genus Mean Chronic Values

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 | 34.19 | Cladoceran, *Ceriodaphnia dubia* | 34.19 | - |
| 15 | 19.42 | Oligochaete, *Aeolosoma headleyi* | 19.42 | - |
| 14 | >18.09 | Blue Tilapia, *Oreochromis aurea* | >18.09 | - |
| 13 | 12.16 | Bluegill, *Lepomis macrochirus* | 12.16[c] | 423.7 |
| 12 | 11.45 | Fathead minnow, *Pimephales promelas* | 11.45[c] | 13.13[c] |
| 11 | 8.389 | Smallmouth bass, *Micropterus dolomieui* | 8.389 | - |
| 10 | 8.356 | Northern pike, *Esox lucius* | 8.356 | - |

Table 3b. Continued

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 |
|---|---|---|---|---|
| 9 | 8.059 | White sucker, *Catostomus commersoni* | 8.059 | - |
| 8 | 6.939 | Atlantic salmon, *Salmo salar* | 9.574 | - |
| | | Brown trout, *Salmo trutta* | 5.029[c] | - |
| 7 | 5.421 | Flagfish, *Jordanella floridae* | 5.421[d] | 433.8 |
| 6 | 4.941 | Snail, *Aplexa hypnorum* | 4.941[c] | 20.76[c] |
| 5 | 4.528 | Brook trout, *Salvelinus fontinalis* | 2.455[d] | - |

Table 3b. Continued

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 |
|---|---|---|---|---|
| | | Lake trout, *Salvelinus namaycush* | 8.351 | - |
| 4 | 2.287 | Coho salmon, *Oncorhynchus kisutch* | 4.404[c] | - |
| | | Rainbow trout, *Oncorhynchus mykiss* | 0.8736 | - |
| | | Chinook salmon, *Oncorhynchus tshawytscha* | 3.108 | 0.9021 |
| 3 | 1.767 | Midge, *Chironomus tentans* | 1.767 | - |
| 2 | 0.1933[f] | Cladoceran, *Daphnia magna* | 0.1933[e] | 104.3[d] |
| | | Cladoceran, *Daphnia pulex* | 5.774[f] | - |

Table 3b. Continued

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 |
|---|---|---|---|---|
| 1 | 0.1811 | Amphipod, *Hyalella azteca* | 0.1811 | - |

[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, ther the most sensitive value used.

Table 4. Toxicity of Cadmium to Aquatic Plants

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect[b] | Result (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 & 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 & Devi Prasad 1982 |
| Blue alga, *Microcystis aeruginosa* | - | Cadmium nitrate | - | - | incipient inhibition | 70 | Bringmann 1975; Bringmann & Kuhn 1976, 1978a,b |
| Green alga. *Scenedesmus quadricauda* | - | Cadmium nitrate | - | - | incipient inhibition | 310 | Bringmann & 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 & Devi Prasad 1982 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Green alga, *Chlorella pyrenoidosa* | - | - | - | - | Reduction in growth | 250 | Hart & Scalfe 1977 |
| Green alga, *Chlorella vulgaris* | - | - | - | - | Reduction in growth | 50 | Hutchinson & Stokes 1975 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total $\mu g/L$)[b] | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | Reference |
|---|---|---|---|---|---|---|---|
| Green alga, *Clorella vulgaris* | - | Cadmium chloride | - | - | 50% reduction in growth | 60 | Rosko & Rachlin 1977 |
| Green alga, *Clorella vulgaris* | - | Cadmium chloride | 50 | - | 96-hr EC50 (growth inhibition) | 3,700 | Canton & 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 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | Reference |
|---|---|---|---|---|---|---|---|
| Green alga, *Selenastrum capricornutum* | S, U | Cadmium chloride | - | 4 days | EC50 growth | 23.2 | Thellen et al. 1989 |
| Green alga, *Selenastrum capricornutum* | S, U | Cadmium chloride | 171 | 4 days | EC50 growth | 130 | Versteeg 1990 |
| 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 & Czyrska 1972 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | Reference |
|---|---|---|---|---|---|---|---|
| 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 1990 |
| Duckweed, *Lemna valdiviana* | - | Cadmium nitrate | - | - | Reduction in number of fronds | 10 | Hutchinson & Czyrska 1972 |
| Duckweed, *Spirodela polyrhiza* | R, U | Cadmium sulfate | - | 28 days | LOEC growth | 7.63 | Sajwan and Ornes 1994 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | 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 & Jones 1981 |
| Diatom, *Ditylum brightwellii* | - | Cadmium chloride | - | - | 5-day EC50 (growth) | 60 | Canterford & Canterford 1980 |
| Diatom, *Phaeodactylum tricornutum* | S, U | Cadmium chloride | 35[c] | 4 days | EC50 growth | 22,390 | Torres et al. 1998 |
| Diatom, *Thalassiosira pseudonana* | - | Cadmium chloride | - | - | 96-hr EC50 (growth rate) | 160 | Gentile & Johnson, 1982 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | Reference |
|---|---|---|---|---|---|---|---|
| Diatom, *Skeletonema costatum* | - | Cadmium chloride | - | - | 96-hr EC50 (growth rate) | 175 | Gentile & Johnson 1982 |
| Red alga, *Champia parvula* | - | Cadmium chloride | - | - | Reduced tetrasporophyte growth | 24.9 | Steele & Thursby 1983 |
| Red alga, *Champia parvula* | - | Cadmium chloride | - | - | Reduced tetrasporangia production | >189 | Steele & Thursby 1983 |
| Red alga, *Champia parvula* | - | Cadmium chloride | - | - | Reduced female growth | 22.8 | Steele & Thursby 1983 |
| Red alga, *Champia parvula* | - | Cadmium chloride | - | - | Stopped sexual reproduction | 22.8 | Steele & Thursby 1983 |

Table 4. (Continued)

| Species | Method[a] | Chemical | Hardness (mg/L as $CaCO_3$) | Duration | Effect | Result (Total µg/L)[b] | Reference |
|---|---|---|---|---|---|---|---|
| Red alga, *Champia parvula* | R, U | Cadmium chloride | 28-30[c] | 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 concentration measured; D= dissolved metal concentration measured.
[b] Results are expressed as cadmium, not as the chemical.
[C] Salinity (g/kg).

Table 5. Bioaccumulation of Cadmium by Aquatic Organisms

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/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 & Czyrska 1972 |
| Fern, *Salvinia natans* | Whole plant | Cadmium nitrate | - | - | 21 | 960 | Hutchinson & 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] | |

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

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| | 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 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| | 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 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| 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 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| 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 |
| 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 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water (µg/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| 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 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| Atlantic salmon, *Salmo salar* | Whole body (egg) | Cadmium chloride | - | 0.87 (pH=6.8)<br>1.74 (pH=6.8)<br>1.01 (pH=4.5)<br>2.09 (pH=4.5) | 91<br>91<br>91<br>91 | 229<br>176<br>4<br>7 | Peterson et al. 1985 |
| 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 & Freeman 1979 |
| Mosquitofish, *Gambusia affinis* | Whole body (estimated steady state) | Cadmium chloride | - | - | 180 | 2,213 | Giesy et al. 1979 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| 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 & Slooff 1982 |
| 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 | |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| Blue tilapia, *Tilapia aurea* | Muscle | Cadmium nitrate | 145 | 6.8<br>14<br>28<br>52 | 112<br>112<br>112<br>112 | 17.6<br>16.4<br>25.7<br>17.7 | Papoutsoglou and Abel 1988 |
| African clawed frog, *Xenopus laevis* | Whole body | - | - | - | 100 | 130 | Canton & 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 |

SALTWATER SPECIES

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| Polychaete worm, *Ophryotrocha diadema* | Whole body | Cadmium chloride | - | - | 64 | 3,160 | Klockner 1979 |
| Blue mussel, *Mytilus edulis* | Soft parts | Cadmium chloride | - | - | 28 | 113 | George & Coombs1977 |
| Blue mussel, *Mytilus edulis* | Soft parts | Cadmium chloride | - | - | 35 | 306 | Phillips 1976 |
| Bay scallop, *Argopecten irradians* | Muscle | Cadmium chloride | - | - | 42 | 2,040 | Pesch & Stewart 1980 |
| Eastern oyster, *Crassostrea virginica* | Soft parts | Cadmium chloride | - | - | 280 | 2,150 | Zaroogian & Cheer 1976 |
| Eastern oyster, *Crassostrea virginica* | Soft parts | Cadmium chloride | - | - | 280 | 1,830 | Zaroogian 1979 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| Eastern oyster, *Crassostrea virginica* | Soft parts | Cadmium nitrate | - | - | 98 | 1,220 | Schuster & 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 & Stewart 1980 |
| Grass shrimp, *Paleomonetes pugio* | Whole body | Cadmium chloride | - | - | 28 | 203 | Nimmo et al. 1977b |
| Grass shrimp, *Paleomonetes vulgaris* | Whole body | Cadmium chloride | - | - | 28 | 307 | Nimmo et al. 1977b |
| Green crab, *Carcinus maenas* | Muscle | Cadmium chloride | - | - | 68 | 5 | Wright 1977 |

Table 5. (Continued)

| Species | Tissue | Chemical | Hardness (mg/L as $CaCO_3$) | Concentration in water ($\mu$g/L)[a] | Duration (days) | BCF or BAF | Reference |
|---|---|---|---|---|---|---|---|
| Green crab, *Carcinus maenas* | Muscle | Cadmium chloride | - | - | 40 | 7 | Jennings & 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 6. Other Data on Effects of Cadmium on Aquatic 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 | 32.0 | - | 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 biomass 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 | 49.39 | - | Radetski et al. 1995 |
| Green alga, *Selenastrum capricornutum* | S, U | Cadmium chloride | 24.2 | 72 hr | EC50 (cell counts) | 42.7 | 102.4 | - | Radetski et al. 1995 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 378.1 | - | 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Bacteria, *Salmonella typhimurium* | - | Cadmium chloride | 50 | 8 hr | EC50 (growth inhibition) | 10,400 | 10,400 | - | Canton and Slooff 1982 |
| Bacteria, *Pseudomonas putida* | - | Cadmium chloride | - | 16 hr | Incipient inhibition | 80 | - | - | Bringmann and Kuhn 1976, 1977a, 1979, 1980b |
| Bacteria, (6 species) | - | Cadmium chloride | - | 18 hr | Reduced growth | 5,000 100,000 | - | - | Seyfried and Horgan 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Protozoan community | S, M, T | Cadmium chloride | 70 | 2 days | EC50 (number of species) | 4,600 | 3,067 | - | Niederlehner et al. 1985 |
| | | | | 28 days | EC20 (colonization) | 1 | - | - | |
| Protozoan community | S, U | Cadmium chloride | - | 240 hr | Reduced biomas | 1 | - | - | Fernandez-Leborans and Novillo-Villajos 1993 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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, 1981 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 157.1<br>757.9 | -<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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Ciliate, *Tetrahymena pyriformis* | S, U | Cadmium chloride | - | 96 hr | EC50 growth | 1,045 | - | - | Schafer et al. 1994 |
| Ciliate, *Tetrahymena pyriformis* | S, U | Cadmium acetate | - | 30 min | Complete mortality | 56,205 | - | - | Larsen and Svensmark 1991 |
| Ciliate, *Colpidium campylum* | S, U | Cadmium sulfate | - | 24 hr | EC50 growth | 75 | - | - | Dive et al. 1989 |
| Ciliate, *Tetrahymena pyriformis* | S, U | Cadmium chloride | - | 9 hr | IC50 growth | 3,000 | - | - | Sauvant et al. 1995 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 13.3 | - | Santiago-Faudino 1983 |
| Planarian, *Dendrocoelum lacteum* | R, M, T | Cadmium chloride | 122.8 | 48 hr | LC50 | 46,000 | 15,580 | - | Brown and Pascoe 1988 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Planarian, *Dugesia lugubris* | - | Cadmium nitrate | - | 48 hr | LC50 | >20,000 | - | - | Slooff 1983 |
| Mixed macro invertebrates | - | Cadmium chloride | 11.1 | 52 wk | Reduced taxa | 5 | 30.7 | - | Giesy et al. 1979 |
| Rotifer, *Brachionus calyciflorus* | S, U | Cadmium nitrate | 80-100 | 72 hr | Chronic value (asexual reproduction) | 20 | 9.9 | - | Snell and Carmona 1995 |
| | | | | | Chronic Value (sexual reproduction) | 20 | 9.9 | - | |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rotifer, *Brachionus calyciflorus* | S, U | Cadmium nitrate | 80-100 | 48 hr | EC50<br>Chronic value | 70<br>60 | 34.5<br>29.6 | -<br>- | Snell and Moffat 1992 |
| Rotifer, *Brachionus calyciflorus* | S, U | Cadmium nitrate | 80-100 | 24 hr | LC50 | 1,300 | 640.3 | - | Snell et al. 1991a |
| Rotifer, *Brachionus rubens* | S, U | Cadmium chloride | 80-100 | 24 hr | LC50<br>NOEC (survival) | 810<br>280 | 398.9<br>137.9 | -<br>- | Snell and Persoone 1989a |
| Rotifer, *Brachionus calyciflorus* | S, U | Cadmium chloride | 170 | 35 min | NOEC (ingestion rate) | 250 | 57.2 | - | Juchelka and Snell 1994 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rotifer, *Brachionus calyciflorus* | S, U | Cadmium nitrate | 80-100 | 48 hr | EC50 | 10 | 4.93 | - | 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 | 52,532 | - | Qureshi et al. 1980 |
| Tubificid worm, *Tubifex tubifex* | R, U | Cadmium chloride | 245 | 96 hr | LC50 | 47,530 | 7,004 | - | Khangarot 1991 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Worm, *Lumbriculus variegatus* | F, M, T | Cadmium chloride | 44-47 | 10 days | LC50 | 158 | 177.0 | - | Phipps et al. 1995 |
| Worm, *Pristina* sp. | - | Cadmium chloride | 11.1 | 52 wk | Population reduction | 5 | 30.7 | - | Giesy et al. 1979 |
| Worm, *Pristina leidyi* | S, M, T | Cadmium chloride | 95 | 48 hr | LC50 | 215 | 99.2 | - | Smith et al. 1991 |
| Nematode, *Caenorhabditis elegans* | S, U | Cadmium chloride | - | 96 hr | LC50 (fed) | 61 | - | - | Williams and Dusenbery 1990 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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)<br>3,800 (pH=4.0)<br>2,710 (pH=4.5) | 26,450<br>15,828<br>1,288 | -<br>-<br>- | Mackie 1989 |
| Snail, *Lymnaea stagnalis* | - | Cadmium chloride | - | 48 hr | LC50 | 583 | - | - | Slooff 1983; Slooff et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Snail, *Physa integra* | - | Cadmium chloride | 44-58 | 28 days | LC50 | 10.4 | 10.2 | - | Spehar et al. 1978 |
| Snail, *Vivpara bengalensis* | S, U | Cadmium chloride | 140-190 | 96 hr | LC50 | 1,550 | 367.8 | - | Gadkari and Marathe 1983 |
| Mussel, *Utterbackia imbecilis* | S, M, T | Cadmium chloride | 39<br>80-100 | 48 hr<br>48 hr | LC50<br>LC50 | 57<br>137 | 76.9<br>67.5 | -<br>- | Keller and Zam 1991 |
| Zebra mussel, *Dreissena polymorpha* | R, M, T | Cadmium chloride | 150 | 48 hr | EC50 | 388 | 103.3 | -<br>- | Kraak et al. 1994a |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Zebra mussel, *Dreissena polymorpha* | R, M, T | Cadmium chloride | 268 | 10 wk | LOEC filtration rate | 9 | 1.19 | - | Kraak et al. 1992b |
| | | | | 11 wk | EC50 | 130 | 17.2 | - | |
| Bivalve, *Pisidium casertanum* | S, M, T | Cadmium chloride | 15.3 | 96 hr | LC50 | 1,370 (pH=3.5) | 5,707 | - | Mackie 1989 |
| | | | | | | 480 (pH=4.0) | 1,999 | - | |
| | | | | | | 700 (pH=4.5) | 2,916 | - | |
| Bivalve, *Pisidium compressum* | S, M, T | Cadmium chloride | 15.3 | 96 hr | LC50 | 2,080 (pH=3.5) | 8,664 | - | Mackie 1989 |
| | | | | | | 700 (pH=4.0) | 2,916 | - | |
| | | | | | | 360 (pH=4.5) | 1,500 | - | |
| Cladoceran (<24 hr) *Ceriodaphnia dubia* | R,M, T | Cadmium nitrate | 100 | 48 hr | LC50 | 27.3 (High TOC) | 11.84 | - | Spehar and Fiandt 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Ceriodaphnia* | R, U | Cadmium sulfate | 169 | 7 days | Chronic value reproduction | <14 | <3.23 | - | Masters et al. 1991 |
| Cladoceran, *Ceriodaphnia dubia* | S, U | Cadmium chloride | 80-100 | 1 hr | EC50 feeding inhibition | 54 | 26.6 | - | Britton et al. 1996 |
| Cladoceran, *Ceriodaphnia dubia* | S, U | Cadmium chloride | 80-100 | 1 hr | EC50 feeding inhibition | 76.2 | 37.5 | - | Lee et al. 1997 |
| Cladoceran (<48 hr), *Ceriodaphnia dubia* | S, M, T | Cadmium nitrate | 280-300 | 48 hr | LC50 (fed) | 560 | 67.3 | - | Schubauer-Berigan et al. 1993 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, U | Cadmium chloride | 80 | 48 hr | LC50 | 49.5 | 28.10 | - | Hockett and Mount 1996 |
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, U | Cadmium chloride | 172 | 48 hr | LC50 | 221 | 49.9 | - | Hockett and Mount 1996 |
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, M, D | Cadmium sulfate | 160-180 | 120 min | Reduced mobility | 2,500 | 572.2 | - | Brent and Herricks 1998 |
| Cladoceran, *Ceriodaphnia dubia* | R, U | Cadmium chloride | 80-100 | 7 days | Chronic value | 1.4 | 0.69 | - | Zuidervee n and Birge 1997 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Ceriodaphnia dubia* | S, U | Cadmium nitrate | 80-100 | 48 hr | LC50 | 78.2 (fed) | 38.51 | - | Nelson and Roline 1998 |
| Cladoceran, *Ceriodaphnia dubia* | R, U | Cadmium sulfate | 90 | 10 days | NOEC reproduction | 0.5 | 0.25 | - | Winner 1988 |
| Cladoceran, *Ceriodaphnia reticulata* | S, M | Cadmium chloride | 55-79 | 48 hr | LC50 | 129 (High TOC) | 90.7 | - | Spehar and Carlson 1984a,b |
| Cladoceran (<6 hr), *Ceriodaphnia reticulata* | S, U | Cadmium chloride | 200 | 48 hr | LC50 | 79.4 | 14.94 | - | Hall et al. 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Ceriodaphnia reticulata* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 1,900 | 2,679 | - | Sharma and Selvaraj 1994 |
| Cladoceran, *Daphnia carinata* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 280 | 394.7 | - | Sharma and Selvaraj 1994 |
| Cladoceran, *Daphnia galeata mendotae* | - | Cadmium chloride | - | 22 wk | Reduced biomass | 4.0 | - | - | Marshall 1978a |
| Cladoceran, *Daphnia galeata mendotae* | - | Cadmium chloride | - | 15 days | Reduced rate of increase | 5.0 | - | - | Marshall 1978b |

Table 6. (Continued)

| | Method | Chemical | ess (mg/L $CaCO_3$ | Duration | | Result (Total µg/L) | Resul Adjusted TH=50 (Tota µ | Result Adjust TH=50 (Disso g/L) | Referenc |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Daphnia* | - | Cadmi chlor ide | | 48 hr | EC50 water) | 100 | | - | Bringmann 1959a,b |
| Cladoceran, *magna* | - | um chlor | 45 | 21 | Reproducti ve | 0.17 | 0.19 | | Biesinger and en 1972 |
| Cladoceran, *magna* | - | um chlor | 163 | 72 hr | | 14-17 | 3.71 | | Debelak 1975 |
| *Daphnia magna* | | Cadmi um te | - | | LC50 | 600 | | - | Bringmann 1977b |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (3-5 days), *Daphnia magna* | - | Cadmium sulfate | - | 72 hr | LC50<br>(10NC)<br>(15NC)<br>(25NC)<br>(30NC) | 224<br>224<br>12<br>0.1 | -<br>-<br>-<br>- | -<br>-<br>-<br>- | Braginskly and Shcherban 1978 |
| Cladoceran (adult), *Daphnia magna* | - | Cadmium sulfate | - | 72 hr | LC50<br>(10NC)<br>(15NC)<br>(25NC)<br>(30NC) | 479<br>187<br>10.2<br>2.4 | -<br>-<br>-<br>- | -<br>-<br>-<br>- | Braginskly and Shcherban 1978 |

| Species | Meth[a] | Chemi | Hardn ess as CaCO ) | Durat | Effect | Result µ [b] | t Adjus to TH=50 l g/L) | Result ed to TH=50 lved µg/L) | e |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *magna* | - | um nitra | 200 | 24 hr | | 160 | 30.1 | | Bellavera and Gorbi |
| Cladoceran, *Daphnia* | - | Cadmi chlor ide | | 96 hr | EC50 | | 1.58 | - | Maly 1982 |
| Cladoceran, *magna* | - | um chlor | 200 | 20 | LC50 | 670 | | - | Canton Slooff 1982 |
| *Daphnia magna* | | Cadmi um ide | 55-79 | | LC50 | 166 TOC) | 116.7 | | Spehar and 1984a,b |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 48 hr | LC50 | 140 | 32.0 | - | Lewis and Weber 1985 |
| Cladoceran, *Daphnia magna* | S, U | Cadmium chloride | 200 | 48 hr | LC50 | 49.0 | 9.22 | - | 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 | 228.3<br>125.7<br>66.2<br>74.8<br>39.2 | -<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 | 22.3<br>91.0 | -<br>- | Nebeker et al. 1986a |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 427.3<br>88.5<br>124.7<br>27.2 | -<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 | 182.3<br>11.8<br>23.7<br>12.7 | -<br>-<br>-<br>- | Nebeker et al. 1986a |
| Cladoceran (5 d), *Daphnia magna* | S, M, T | Cadmium chloride | 34 | 48 hr | LC50 | 24 | 38.2 | - | Nebeker et al. 1986b |
| Cladoceran (5 d), *Daphnia magna* | R, M, T | Cadmium chloride | 225 | 21 days | LOEC reproduction | 2.3 | 0.38 | - | Enserink et al. 1993 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Daphnia magna* | S, U | Cadmium chloride | - | 48 hr | LC50 | 48 (fed) | - | - | Domal-Kwiatkowska et al. 1994 |
| Cladoceran (14 days), *Daphnia magna* | S, M, T | Cadmium chloride | 160-180 | 48 hr | LC50 | 80 | 18.3 | - | Allen et al. 1995 |
| Cladoceran (egg), *Daphnia magna* | S, M, T | Cadmium chloride | 150 | 46 hr | Profound effect on egg development | >1,000 | >266.1 | - | Bodar et al. 1989 |

Table 6. (Continued)

| | Method | Chemical | ess (mg/L $CaCO_3$ | Duration | | Result (Total µg/L) | Resul Adjusted TH=50 (Total µg/L) | Result ed to TH=50 lved µg/L) | e |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *magna* | S, U | um chlor | 250 | 48 hr | LC50 (small<br>LC50 (large | 98<br>294 | 42.3 | - | Enserink et al. |
| Cladoceran (<24 hr), *magna* | S, | Cadmium ide | 160- | 48 hr | LC50 NC)<br>LC50 (26 C) (fed) | 9 | 8.70 | -<br>- | Horning 1991 |
| *Daphnia magna* | | Cadmium te | - | | EC50 | 980 | | - | Sorvari Sillanpaa 1996 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Daphnia magna* | R, M, T | Cadmium chloride | - | 24 hr<br>24 days | EC50<br>NOEC reproduction | 1,900<br>0.6 | -<br>- | -<br>- | Kuhn et al. 1989 |
| Cladoceran, *Daphnia magna* | R, U | Cadmium sulfate | 90 | 10 days | NOEC reproduction | 2.5 | 1.23 | - | Winner 1988 |
| Cladoceran, *Daphnia magna* | R, U | Cadmium sulfate | 100 | 25 days | NOEC (20NC) reproduction<br>NOEC (25NC) reproduction | 2.25<br>0.75 | 0.98<br>0.33 | -<br>- | Winner and Whitford 1987 |

| Species | Meth[a] | Chemi | Hardn ess as CaCO ) | Durat | Effect | Result μ [b] | t Adjus to TH=50 l g/L) | Result ed to TH=50 lved μg/L) | e |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *pulex* | - | um chlor | 57 | 140 | Reduced reproducti | 1 | 0.85 | | Bertram and Hart |
| Cladoceran, *Daphnia* | - | Cadmi chlor ide | | 48 hr | LC50 (fed) | | 44.5 | - | and Winner |
| Cladoceran, *Daphnia* | - | Cadmi chlor ide | | 58 days | | 5-10 | 2.87 | | Ingersoll and 1982 |
| Cladoceran, *pulex* | - | um sulfa | 100 | 72 hr | | 80-92 | 37.2 | | Winner 1984 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran (<24 hr), *Daphnia pulex* | S, U | Cadmium chloride | 200 | 48 hr | LC50 | 100 | 18.81 | - | Hall et al. 1986 |
| Cladoceran (adult), *Daphnia pulex* | S, U | Cadmium chloride | 124-130 | 48 hr | LC50 | 87.9 | 28.6 | - | Jindal and Verma 1990 |
| Cladoceran (<24 hr), *Daphnia pulex* | S, M, T | Cadmium chloride | 80-90 | 48 hr | LC50 | 24 | 12.7 | - | Lewis and Weber 1985 |
| Cladoceran (<24 hr), *Daphnia pulex* | S, M, T | Cadmium chloride | 80-90 | 48 hr | LC50 (20NC) (fed) | 42 | 22.2 | - | Lewis and Horning 1991 |
| | | | | | LC50 (26NC) (fed) | 6 | 3.17 | - | |

| Species | Meth[a] | Chemi | Hardn ess as CaCO ) | Durat | Effect | Result µ [b] | t Adjus to TH=50 l g/L) | Result ed to TH=50 lved µg/L) | e |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran *Daphnia pulex* | | Cadmi um ide | 80-90 | days | NOEC on | <0.003 | 2 | - | al. 1993 |
| Cladoceran *Daphnia pulex* | M, T | Cadmi chlor ide | 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 | 3.17<br>2.75<br>1.19 | -<br>-<br>- | Winner 1986 |
| Cladoceran, *Moina macrocopa* | - | Cadmi um chlor ide | 80-84 | 20 days | Reduced survival | 0.2 | 0.11 | - | Hatakeyam a and Yasuno 1981b |
| Cladoceran, *Moina macrocopa* | R, M, T | Cadmi um chlor ide | - | 240 hr | Reduced survival | 10 | - | - | Wong and Wong 1990 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Cladoceran, *Moina macrocopa* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 320 | 451.1 | - | Sharma and Selvaraj 1994 |
| Cladoceran, *Simocephalus serrulatus* | S, M | Cadmium chloride | 55-79 | 48 hr | LC50 | 123 (high TOC) | 86.4 | - | Spehar and Carlson 1984a,b |
| Cladoceran, *Simocephalus vetulus* | S, M | Cadmium chloride | 55-79 | 48 hr | LC50 | 89.3 (high TOC) | 62.76 | - | Spehar and Carlson 1984a,b |
| Copepod, *Acanthocyclops viridis* | - | Cadmium sulfate | - | 72 hr | LC50 | 0.5 | - | - | Braginskly and Shcherban 1978 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Copepod, *Eucyclops agilis* | - | Cadmium chloride | 11.1 | 52 wk | Population reduction | 5 | 30.7 | - | Giesy et al. 1979 |
| Copepod, *Mesocyclops hyalinus* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 870 | 1,227 | - | Sharma and Selvaraj 1994 |
| Copepod, *Heliodinptomus vidus* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 150 | 211.5 | - | Sharma and Selvaraj 1994 |
| Copepod, *Tropocyclops prasinus mexicanus* | S, U | Cadmium chloride | 10 | 48 hr | LC50 | 149 | 1,036 | - | Lalande and Pinel-Alloul 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Copepod, *Stenocypris malcolmsoni* | S, M, T | Cadmium sulfate | 37.6 | 48 hr | LC50 | 11,500 | 16,212 | - | Sharma and Selvaraj 1994 |
| Amphipod, *Diporeia* sp. | S, M, T | Cadmium chloride | - | 96 hr | LC50 (4NC)<br>LC50 (10NC)<br>LC50 (15NC) | 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 | 38.23 | - | Spehar and Carlson 1984a,b |
| Amphipod, *Hyalella azteca* | S, M | Cadmium chloride | 217-301 | 24 hr | LC50 | 140 | 19.3 | - | McNulty et al. 1999 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Amphipod, *Hyalella azteca* | S, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 285 (high TOC) | 200.3 | - | Spehar and Carlson 1984a,b |
| 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) | 49.98<br>66.65<br>137.5 | -<br>-<br>- | Mackie 1989 |
| Amphipod (0-2 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈13 | ≈6.4 | - | Collyard et al. 1994 |
| Amphipod (2-4 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈7.5 | ≈3.7 | - | Collyard et al. 1994 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Amphipod (4-6 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈9.5 | ≈4.7 | - | Collyard et al. 1994 |
| Amphipod (10-12 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈7 | ≈3.4 | - | Collyard et al. 1994 |
| Amphipod (16-18 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈11.5 | ≈5.7 | - | Collyard et al. 1994 |
| Amphipod (24-26 d), *Hyalella azteca* | S, M, T | Cadmium chloride | 90 | 96 hr | LC50 | ≈14 | ≈6.9 | - | Collyard et al. 1994 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Amphipod, *Hyalella azteca* | R, M, T | Cadmium nitrate | 130 | 6 wk | EC50 | 0.53 | 0.17 | - | Borgmann et al. 1991 |
| Amphipod, *Hyalella azteca* | F, M, T | Cadmium chloride | 44-47 | 10 days | LC50 | 2.8 | 3.14 | - | Phipps et al. 1995 |
| Amphipod, *Hyalella azteca* | S, M, T | Cadmium nitrate | 280-300 | 96 hr | LC50 (fed) | 230 | 27.7 | - | Schubauer-Berigan et al. 1993 |
| Crayfish, *Cambarus latimanus* | - | Cadmium chloride | 11.1 | 5 mo | Significant mortality | 5 | 30.7 | - | Thorp et al. 1979 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Crayfish, *Orconectes immunis* | S, M, T | Cadmium chloride | 50.3 | 96 hr | LC50 | >10,000 | >9,928 | - | Thorp and Gloss 1986 |
| Anostracan crustacean, *Brachionus calyciflorus* | S, U | Cadmium sulfate | 250 | 24 hr | EC50 | 120 | 17.3 | - | Crisinel et al. 1994 |
| Anostracan crustacean, *Streptocephalus rubricaudatus* | S, U | Cadmium sulfate | 250 | 24 hr | EC50 | 250 | 36.0 | - | Crisinel et al. 1994 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Anostracan crustacean, *Thamnocephalus platyurus* | S, U | Cadmium chloride | 80-100 | 24 hr | LC50 | 400 | 197.0 | - | Centeno et al. 1995 |
| Mayfly, *Cloeon dipterum* | - | Cadmium sulfate | - | 72 hr | LC50<br>(10NC)<br>(15NC)<br>(25NC)<br>(30NC) | 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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) | 29,366<br>36,072<br>44,403 | -<br>-<br>- | Mackie 1989 |
| Mayfly, *Ephemerella* sp. | - | Cadmium chloride | 44-48 | 28 days | LC50 | <3.0 | <3.3 | - | Spehar et al. 1978 |
| Mayfly, *Paraleptophiebia praepedita* | S, M | Cadmium chloride | 55-77 | 96 hr | LC50 | 449 | 315.6 | - | Spehar and Carlson 1984a,b |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Mayfly, *Hexagenia rigida* | - | Cadmium nitrate | 79.1 | 96 hr | LC50 | ≥1,000 | ≥575.4 | - | 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 | 18,557 | - | Khangarot and Ray 1989b |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Midge (1st instar), *Chironomus riparius* | S, M, T | - | 100 | 1 hr | Reduced emergence | 2,100 | 911.0 | - | McCahon and Pascoe 1991 |
| | | | | 10 hr | Reduced emergence | 210 | 91.1 | - | |
| Midge (4th instar), *Chironomus riparius* | S, M, T | - | 100 | 1 hr | Reduced emergence | 2,000 | 867.6 | - | McCahon and Pascoe 1991 |
| | | | | 10 hr | Reduced emergence | 200 | 86.8 | - | |
| Midge (1st instar), *Chironomus riparius* | R, M, T | - | 98 | 17 days | LOEC survival, development and growth | 150 | 66.7 | - | Pascoe et al. 1989 |
| Midge (2nd instar), *Chironomus riparius* | R, M, T | Cadmium chloride | 100-110 | 96 hr | LC50 (fed) | 13,000 | 5,317 | - | Williams et al. 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Midge (3rd instar), *Chironomus riparius* | R, M, T | Cadmium chloride | 100-110 | 96 hr | LC50 (fed) | 22,000 | 8,999 | - | Williams et al. 1986 |
| Midge (4th instar), *Chironomus riparius* | R, M, T | Cadmium chloride | 100-110 | 96 hr | LC50 (fed) | 54,000 | 22,088 | - | Williams et al. 1986 |
| Midge, *Chironomus riparius* | S, U | Cadmium chloride | 98 | 120 hr | LOEC (egg viability) | 30,000 | 13,335 | - | Williams et al. 1987 |
| | | | | 10 days | LOEC (number of eggs ovipositioned) | 100,000 | 44,449 | - | |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Midge, *Tanytarsus dissimilis* | - | Cadmium chloride | 47 | 10 days | LC50 | 3.8 | 4.09 | - | Anderson et al. 1980 |
| Coho salmon (juvenile), *Oncorhynchus kisutch* | - | Cadmium chloride | 22 | 217 hr | LC50 | 2.0 | 5.38 | - | Chapman and Stevens 1978 |
| Coho salmon (adult), *Oncorhynchus kisutch* | - | Cadmium chloride | 22 | 215 hr | LC50 | 3.7 | 9.95 | - | Chapman and Stevens 1978 |
| Coho salmon (alevin), *Oncorhynchus kisutch* | S, U | Cadmium chloride | 41 | 96 hr | LC50 | 6.0 | 7.62 | - | Buhl and Hamilton 1991 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Chinook salmon (alevin), *Oncorhynchus tshawytscha* | - | Cadmium chloride | 23 | 200 hr | LC10 | 18-26 | 55.1 | - | Chapman 1978 |
| Chinook salmon (swim-up), *Oncorhynchus tshawytscha* | - | Cadmium chloride | 23 | 200 hr | LC10 | 1.2 | 3.06 | - | Chapman 1978 |
| Chinook salmon (parr), *Oncorhynchus tshawytscha* | - | Cadmium chloride | 23 | 200 hr | LC10 | 1.3 | 3.31 | - | Chapman 1978 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Chinook salmon (smolt), *Oncorhynchus tshawytscha* | - | Cadmium chloride | 23 | 200 hr | LC10 | 1.5 | 3.82 | - | 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 | 19.7 | - | Black and Birge 1980 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, *Oncorhynchus mykiss* | - | - | 112 | 18 mo | Reduced survival | 0.2 | 0.08 | - | Birge et al. 1981 |
| Rainbow trout, (embryo, larva) *Oncorhynchus mykiss* | - | Cadmium chloride | 104 | 28 days | EC50 (death and deformity) | 140 | 57.9 | - | Birge 1978; Birge et al. 1980 |
| Rainbow trout, *Oncorhynchus mykiss* | - | - | - | 240 hr | LC50 | 75 | - | - | Kumada et al. 1973 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout (adult), *Oncorhynchus mykiss* | - | Cadmium chloride | 54 | 408 hr | LC50 | 5.2 | 4.73 | - | Chapman and Stevens 1978 |
| Rainbow trout (alevin), *Oncorhynchus mykiss* | - | Cadmium chloride | 23 | 186 hr | LC10 | >6 | >15.3 | - | Chapman 1978 |
| Rainbow trout (swim-up), *Oncorhynchus mykiss* | - | Cadmium chloride | 23 | 200 hr | LC10 | 1.0 | 2.55 | - | Chapman 1978 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout (parr), *Oncorhynchus mykiss* | - | Cadmium chloride | 23 | 200 hr | LC10 | 0.7 | 1.78 | - | Chapman 1978 |
| Rainbow trout (smolt), *Oncorhynchus mykiss* | - | Cadmium chloride | 23 | 200 hr | LC10 | 0.8 | 2.04 | - | Chapman 1978 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium sulfate | 326 | 96 hr | LC20 | 20 | 2.09 | - | Davies 1976 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium stearate | - | 10 wk | BCF = 27<br>BCF = 40 | - | - | - | Kumada et al. 1980 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium acetate | - | 10 wk | BCF = 63 | - | - | - | Kumada et al. 1980 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 125 | 10 days | LC50 (18NC)<br>(12NC)<br>(6NC) | 10-30<br>30<br>10-30 | 5.74<br>9.95<br>5.74 | -<br>-<br>- | Roch and Maly 1979 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium sulfate | 240 | 234 days | Increased gill diffusion | 2 | 0.30 | - | Hughes et al. 1979 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 320 | 4 mo | Physiological effects | 10 | 1.07 | - | Arillo et al. 1982, 1984 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 98.6 | 47 days | Reduced growth and survival | 100 | 44.1 | - | Woodworth and Pascoe 1982 |
| Rainbow trout, (embryo, larva) *Oncorhynchus mykiss* | - | Cadmium sulfate | 100 | 62 days | Reduced Survival | <5 | <2.17 | - | Dave et al. 1981 |
| Rainbow trout (larva), *Oncorhynchus mykiss* | - | Cadmium chloride | 89-107 | 7 days | LC50 | 700 | 311.1 | - | Birge et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout (larva), *Oncorhynchus mykiss* | - | Cadmium chloride | 89-107 | 7 days | LC50 after 24 days acclimated to 5.9 µg/L | 1,590 | 706.7 | - | 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) | 7.17 | - | Spehar and Carlson 1984a,b |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 82 | 11 days | LC50 (10NC) | 16.0 | 8.81 | - | Majewski and Giles 1984 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 82 | 8 days | LC50 (15NC) | 16.6 | 9.15 | - | Majewski and Giles 1984 |
| Rainbow trout, *Oncorhynchus mykiss* | - | Cadmium chloride | 82 | 178 days | Physiological effects | 3.6-6.4 | 2.65 | - | Majewski and Giles 1984 |
| Rainbow trout, (egg-0 hr) *Oncorhynchus mykiss* | R, U | Cadmium chloride | 50 | 96 hr | LC50 | 13,000 | 13,000 | - | Van Leeuwen et al. 1985a |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, (sac fry-42 d) *Oncorhynchus mykiss* | R, U | Cadmium chloride | 50 | 96 hr | LC50 | 30 | 30 | - | Van Leeuwen et al. 1985a |
| Rainbow trout, (early fry-77 d) *Oncorhynchus mykiss* | R, U | Cadmium chloride | 50 | 96 hr | LC50 | 10 | 10 | - | 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 | 984.0<br>300.2 | -<br>- | Pascoe et al. 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, (5 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | >100,000 | >50,812 | - | Shazili and Pascoe 1986 |
| Rainbow trout, (10 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 3,300 | 1,677 | - | Shazili and Pascoe 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, (15 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 7,200 | 3,658 | - | Shazili and Pascoe 1986 |
| Rainbow trout, (22 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 8,000 | 4,065 | - | Shazili and Pascoe 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, (29 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 12,500 | 6,352 | - | Shazili and Pascoe 1986 |
| Rainbow trout, (36 d post fertilization) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 16,500 | 8,384 | - | Shazili and Pascoe 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout, (alevin, 2 d post hatch) *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 87.7 | 48 hr | LC50 | 5,800 | 2,947 | - | 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 | 4,217 | - | Shazili and Pascoe 1986 |
| Rainbow trout (alevin), *Oncorhynchus mykiss* | S, U | Cadmium chloride | 41 | 96 hr | LC50 | 37.9 | 48.14 | - | Buhl and Hamilton 1991 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout (fry), *Oncorhynchus mykiss* | F, M, T | Cadmium chloride | 9.2 | 96 hr | LC50 | 28 (pH=4.7) 0.7 (pH=5.7) | 215.3 5.382 | - - | Cusimano et al. 1986 |
| Rainbow trout (36 g), *Oncorhynchus mykiss* | F, M, T | - | 50 | 96 hr | LC50 | 2.7 | 2.70 | - | Davies et al. 1993 |
| Rainbow trout (36 g), *Oncorhynchus mykiss* | F, M, T | - | 200 | 96 hr | LC50 | 3.2 | 0.602 | - | Davies et al. 1993 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Rainbow trout (36 g), *Oncorhynchus mykiss* | F, M, T | - | 400 | 96 hr | LC50 | 7.6 | 0.620 | - | Davies et al. 1993 |
| Brown trout, *Salmo trutta* | S, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 15.1 | 10.61 | - | Spehar and Carlson 1984a,b |
| Atlantic salmon, *Salmo salar* | - | Cadmium chloride | 13 | 70 days | Reduced growth | 2 | 10.1 | - | Peterson, 1983 |
| Atlantic salmon, (alevin) *Salmo salar* | R, M, T | Cadmium chloride | 28 | 92 days | Net water uptake inhibited | 0.78 | 1.57 | - | Rombough and Garside 1984 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Brook trout, *Salvelinus fontinalis* | - | Cadmium chloride | 10 | 21 days | Testicular damage | 10 | 69.5 | - | Sangalang and O'Halloran 1972, 1973 |
| Brook trout (8 months), *Salvelinus fontinalis* | R, M, T | - | 20 | 10 days | NOEL survival | 8 | 24.1 | - | Jop et al. 1995 |
| Lake trout, *Salvelinus namaycush* | F, M, T | Cadmium chloride | 90 | 8-9 mo | Decreased thyroid follicle epithelial cell height | 5 | 2.46 | - | Scherer et al. 1997 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Arctic grayling (alevin), *Thymallus arcticus* | S, U | Cadmium chloride | 41 | 96 hr | LC50 | 6.1 (1-d acclimation) | 7.748 | - | Buhl and Hamilton 1991 |
| Arctic grayling (juvenile), *Thymallus arcticus* | S, U | Cadmium chloride | 41 | 96 hr | LC50 | 4.0 (low D.O.) | 5.081 | - | Buhl and Hamilton 1991 |
| Goldfish, (embryo, larva), *Carassius auratus* | - | Cadmium chloride | 195 | 7 days | EC50 (death and deformity) | 170 | 32.98 | - | Birge 1978 |
| Goldfish, *Carassius auratus* | - | - | - | 50 days | Reduced plasma sodium | 44.5 | - | - | McCarty and Houston 1976 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Common carp (embryo), *Cyprinus carpio* | - | Cadmium sulfate | 360 | - | EC50 (hatch) | 2,094 | 194.1 | - | Kapur and Yadav 1982 |
| Common carp (fry), *Cyprinus carpio* | S, U | - | 100 | 96 hr | LC50 | 4,260 | 1,848 | - | Suresh et al. 1993a |
| Common carp (fingerling), *Cyprinus carpio* | S, U, | - | 100 | 96 hr | LC50 | 17,050 | 7,396 | - | Suresh et al. 1993a |
| Common carp (embryo, larva), *Cyprinus carpio* | F, M, T | Cadmium chloride | 101.6 | 8 days | LC50 (multiple-species test) | 139 | 59.17 | - | Birge et al. 1985 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Common shiner (0.75-3.5 mg), *Notropis cornutus* | R, M, D | Cadmium chloride | 48 | 7 days | 67% reduced growth | 200 | 210.1 | - | Borgmann and Ralph 1986 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 63 | 96 hr | LC50 | 80.8 | 61.16 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 55 | 96 hr | LC50 | 40.9 | 36.46 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 59 | 96 hr | LC50 | 64.8 | 53.08 | - | Spehar 1982 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 66 | 96 hr | LC50 | 135 | 96.61 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 65 | 96 hr | LC50 | 120 | 87.47 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 74 | 96 hr | LC50 | 86.3 | 53.81 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 79 | 96 hr | LC50 | 86.6 | 49.91 | - | Spehar 1982 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 62 | 96 hr | LC50 | 114 | 87.97 | - | Spehar 1982 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 63 | 96 hr | LC50 | 80.8 | 61.16 | - | 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 | 2,512 | - | Birge et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | 254-271 | 3.7 hr | LT50 | 16,000 | 2,170 | - | Birge et al. 1983 |
| Fathead minnow (larva), *Pimephales promelas* | - | Cadmium chloride | 89-107 | 7 days | LC50 | 200 | 88.9 | - | 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 | 240.0 | - | Birge et al. 1983 |
| Fathead minnow, *Pimephales promelas* | - | Cadmium chloride | - | 4 days | Histological effects | 12,000 | - | - | Stromberg et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow, *Pimephales promelas* | - | Cadmium nitrate | 209 | 48 hr | LC50 | 802 | 143.1 | - | Slooff et al. 1983 |
| Fathead minnow, *Pimephales promelas* | S, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 3,390 | 2,383 | - | Spehar and Carlson 1984a,b |
| Fathead minnow, *Pimephales promelas* | F, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 1,830 | 1,286 | - | Spehar and Carlson 1984a,b |
| Fathead minnow (1-7 d), *Pimephales promelas* | R, M, T | Cadmium chloride | 70-90 | 48 hr | LC50 | 35.4 | 20.09 | - | Diamond et al. 1997 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow (embryo, larva), *Pimephales promelas* | F, M, T | Cadmium chloride | 101.6 | 8 days | LC50 | 125(20.1NC)<br>84 (22.8NC)<br>76 (25.7NC)<br>87 (27.9NC) | 53.19<br>35.75<br>32.34<br>37.03 | -<br>-<br>-<br>- | Birge et al. 1985 |
| Fathead minnow (embryo, larva), *Pimephales promelas* | R, M, T | Cadmium chloride | 101.6 | 8 days | LC50<br>NOEC | 41<br>12 | 17.45<br>5.107 | -<br>- | Birge et al. 1985 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Fathead minnow (embryo, larva), *Pimephales promelas* | F, M, T | Cadmium chloride | 101.6 | 8 days | LC50 (multiple-species test) | 107 | 45.54 | - | Birge et al. 1985 |
| Fathead minnow (30 d), *Pimephales promelas* | F, M, T | Cadmium nitrate | 44 | 96 hr | LC50 | 13.2 | 15.40 | - | Spehar and Fiandt 1986 |
| Fathead minnow (14-30 d), *Pimephales promelas* | S, U | Cadmium chloride | 200 | 96 hr | LC50 | 90 | 16.94 | - | Hall et al. 1986 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| White sucker (larva), *Catostomus commersoni* | R, M, D | Cadmium chloride | 48 | 7 days | 46% reduced growth | 36 | 37.8 | - | 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Channel catfish, *Ictalurus punctatus* | S, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 7,940 | 5,581 | - | Spehar and Carlson 1984a,b |
| Walking catfish, *Clarias batrachus* | S, U | Cadmium chloride | - | 14 days | 60% mortality | 8,993 | - | - | Jana and Sahana 1989 |
| Mummichog, *Fundulus heteroclitus* | S, U | Cadmium chloride | 5 | 96 hr | TL50 | 12.2 | 195.6 | - | 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 8,243 | - | Chagnon and Guttman 1989 |
| Guppy, *Poecilla reticulata* | - | Cadmium nitrate | 209 | 48 hr | LC50 | 41,900 | 7,478 | - | Slooff et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 593.2<br>3,025<br>3,796 | -<br>-<br>- | Gadkaic and Marathe 1983 |
| Threespine stickleback, *Gasterosteus aculeatus* | F, M, T | Cadmium sulfate | 299 | 18 days | Kidney cell tissue breakdown | 6,000 | 695.5 | - | Oronsaye 1989 |
| Bluegill, *Lepomis macrochirus* | - | Cadmium chloride | 112 | 80 min | Significant avoidance | >41.1 | >15.55 | - | Black and Birge 1980 |
| Bluegill, *Lepomis macrochirus* | - | Cadmium chloride | 340-360 | 3 days | Increased cough rate | 50 | 4.79 | - | Bishop and McIntosh 1981 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Bluegill, *Lepomis macrochirus* | S, M | Cadmium chloride | 55-79 | 96 hr | LC50 | 8,810 | 6,192 | - | Spehar and Carlson 1984a,b |
| Bluegill (31.1 ± 1.3 mm) *Lepomis macrochirus* | F, M, T | Cadmium chloride | 174 | 22 days | LOEC prey attack rate | 37.3 | 8.30 | - | Bryan et al. 1995 |
| Largemouth bass, *Micropterus salmoides* | - | Cadmium chloride | 112 | 80 min | Significant avoidance | 8.83 | 3.34 | - | Black and Birge 1980 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Largemouth bass, (embryo, larva) *Micropterus salmoides* | - | Cadmium chloride | 99 | 8 days | EC50 (death and deformity) | 1,640 | 720.1 | - | 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 | 103.8 | - | Birge et al. 1985 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Orangethroat darter (embryo), *Etheostoma spectabile* | R, M, T | Cadmium chloride | 180 | 96 hr | LC50 | >500 | >106.8 | - | 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 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Tilapia (72 hr), *Oreochromis mossambica* | S, U | Cadmium chloride | 28 | 96 hr | LC50 | 21.4 | 43.04 | - | Chang et al. 1998 |
| Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis* | - | Cadmium chloride | 195 | 7 days | EC50 (death and deformity) | 40 | 7.76 | - | Birge 1978 |
| African clawed frog, *Xenopus laevis* | - | Cadmium nitrate | 209 | 48 hr | LC50 | 11,700 | 2,088 | - | Slooff and Baerselman 1980; Slooff et al. 1983 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| African clawed frog, *Xenopus laevis* | - | - | 170 | 48 hr | LC50 | 3,200 | 732.4 | - | Canton and Slooff 1982 |
| African clawed frog, *Xenopus laevis* | - | - | 170 | 100 days | Inhibited development | 650 | 148.8 | - | 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 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 50.6 | - | Nebeker et al. 1994 |
| Northwestern salamander, *Ambystoma gracile* | F, M, T | Cadmium chloride | 45 | 10 days | LOAEL growth | 227 | 257.7 | - | Nebeker et al. 1995 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Marbled salamander (embryo, larva), *Ambystoma opacum* | - | Cadmium chloride | 99 | 8 days | EC50 (death and deformity) | 150 | 65.9 | - | Birge et al. 1978 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Lake study, Periphyton and amphipods | S, M, T | Cadmium chloride | - | 120 days | BCF = 64,000 (periphyton) BCF = 24,000 (*Hyalella azteca*) | - - | - - | - - | Stephenson and Turner 1993 |
| Stream microcosm | F, M, T | Cadmium nitrate | - | 21 days | No effect on periphyton structure, but adverse effect on invertebrate grazers and collectors | 22 | - | - | Selby et al. 1985 |

Table 6.
(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 | | | | |
| 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 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Clam, *Macoma balthica* | R, M | Cadmium chloride | - | 144 hr | LC50 | 1,710 | - | - | McLeese and Ray 1986 |
| Blue mussel, *Mytilus edulis* | - | Cadmium EDTA | - | 28 days | BCF = 252 | - | - | - | George and Coombs 1977 |
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Eastern oyster, *Crassostrea virginica* | - | Cadmium iodide | - | 40 days | BCF = 677 | - | - | - | Kerfoot and Jacobs 1976 |
| Eastern oyster, *Crassostrea virginica* | - | Cadmium chloride | - | 21 days | BCF = 149 | - | - | - | Eisler et al. 1972 |
| Eastern oyster, *Crassostrea virginica* | - | Cadmium chloride | - | 2 days | Reduction in embryonic development | 15 | - | - | Zaroogian and Morrison 1981 |
| Pacific oyster, *Crassostrea gigas* | - | Cadmium chloride | - | 6 days | 50% reduction in settlement | 20-25 | - | - | Watling 1983b |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 | - | - | DeLisle and Roberts 1994 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Pink shrimp, *Penaeus duorarum* | - | Cadmium chloride | - | 30 days | LC50 | 720 | - | - | Nimmo et al. 1977b |
| White shrimp, *Penaeus setiferus* | S, M, T | Cadmium chloride | 11 | 96 hr | LC50 | 990 | - | - | Vanegas et al. 1997 |
| Grass shrimp, *Palaemonetes pugio* | - | Cadmium chloride | - | 42 days | LC50 | 300 | - | - | Pesch and Stewart 1980 |
| Grass shrimp, *Palaemonetes pugio* | - | Cadmium chloride | 5 | 21 days | LC25 | 50 | - | - | Vernberg et al. 1977 |
| Grass shrimp, *Palaemonetes pugio* | - | Cadmium chloride | 10 | 21 days | LC10 | 50 | - | - | Vernberg et al. 1977 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Grass shrimp, *Palaemonetes pugio* | - | Cadmium chloride | - | 29 days | LC50 | 120 | - | - | Nimmo et al. 1977b |
| American lobster, *Homarus americanus* | - | Cadmium chloride | - | 21 days | BCF = 25 | - | - | - | Eisler et al. 1972 |
| American lobster, *Homarus americanus* | - | Cadmium chloride | - | 30 days | Increase in ATPase activity | 6 | - | - | Tucker 1979 |
| Hermit crab, *Pagurus longicarpus* | - | Cadmium chloride | - | 7 days | 25% mortality | 270 | - | - | Eisler and Hennekey 1977 |
| Hermit crab, *Pagurus longicarpus* | - | Cadmium chloride | - | 60 days | LC56 | 70 | - | - | Pesch and Stewart 1980 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |
| Mud crab (larva), *Eurypanopeus depressus* | - | Cadmium chloride | - | 44 days | Delay in metamorphysis | 10 | - | - | Mirkes et al. 1978 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Red sea urchin, *Strongylocentrotus franciscanus* | S, M, T | Cadmium chloride | 30 | 80 min | EC50 (sperm-fert.) | 12,000 | - | - | Dinnel et al. 1989 |
| Purple sea urchin, *Strongylocentrotus purpuratus* | S, M, T | Cadmium chloride | 30 | 80 min | EC50 (sperm-fert.) | 18,000 | - | - | Dinnel et al. 1989 |
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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. 1979a |
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Pacific herring (embryo), *Clupea harengus pallasi* | - | Cadmium chloride | - | 48 hr | Reduced osmolality of perivitelline 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 |
| Sheepshead minnow, *Cyprinodon variegatus* | S, M, T, D | Cadmium chloride | 5<br>15<br>25 | 96 hr<br>96 hr<br>96 hr | LC50 (fed)<br>LC50 (fed)<br>LC50 (fed) | 180<br>312<br>496 | -<br>-<br>- | -<br>-<br>- | Hall et al. 1995 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Atlantic silverside, *Menidia menidia* | - | Cadmium chloride | 12 | 19 days | LC50 | <160 | - | - | Voyer et al. 1979 |
| Atlantic silverside, *Menidia menidia* | - | Cadmium chloride | 20 | 19 days | LC50 | 540 | - | - | Voyer et al. 1979 |
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| Spot (larva), *Leiostomus xanthurus* | - | Cadmium chloride | - | 9 days | Incipient LC50 | 200 | - | - | Middaugh and Dean 1977 |
| Cunner (adult), *Tautogolabrus adspersus* | - | Cadmium chloride | - | 60 days | 37.5% mortality | 100 | - | - | MacInnes et al. 1977 |
| Cunner (adult), *Tautogolabrus adspersus* | - | Cadmium chloride | - | 30 days | Depressed gill tissue oxygen consumption | 50 | - | - | MacInnes et al. 1977 |
| Cunner (adult), *Tautogolabrus adspersus* | - | Cadmium chloride | - | 96 hr | Decreased enzyme activity | 3,000 | - | - | Gould and Karolus 1974 |

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|
| 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.

Table 6. (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 |
|---|---|---|---|---|---|---|---|---|---|

## REFERENCES


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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Amiard-Triquet, C., J.C. Amiard, B. Berthet and C. Metayer. 1988. Field and experimental study of the bioaccumulation of some trace metals in a coastal

food chain: seston, oyster (*Crassostrea gigas*), drill (*Ocenebra erinacea*). Water Sci. Tech. 20(6/7): 13-21.

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

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

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

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

Andres, S., M. Baudrimont, Y. Lapaquellerie, F. Ribeyre, N. Maillet, C. Latouche and A. Boudou. 1999. Field transplantation of the freshwater bivalve *Corbicula fluminea* along a polymetallic contamination gradient (River Lot, France): I. Geochemical characteristics of sampling sites and cadmium and zinc bioaccumulation kinetics. Environ. Toxicol. Chem. 18(11): 2462-2471.
Andros, J.D. and R.R. Garton. 1980. Acute lethality of copper, cadmium, and zinc to northern squawfish. Trans. Am. Fish. Soc. 109: 235.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Birge, W.J., J.A. Black and A.G. Westerman. 1985. Short-term fish and amphibian embryo-larval tests for determining the effects of toxicant stress

on early life stages and estimating chronic values for single compounds and complex effluents. Environmental Toxicology and Chemistry. 4: 807-821.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Brown, A.F. and D. Pascoe. 1988. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates 5. The acute toxicity of cadmium to twelve species of predatory macroinvertebrates. Arch. Hydrobiol. 114(2): 311-319.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Carroll, J.J., et al. 1979. Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*). Bull. Environ. Contam. Toxicol. 22:575.

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

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

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

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

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

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

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

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

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

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

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

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

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

Chandini, T. 1988a. Changes in food (*Chlorella*) levels and the acute toxicity of cadmium to *Daphnia carinata* (daphnidae) and *Echinisca triserialis*

(macrothricidae) (Crustacea: cladocera). Bull. Environ. Contam. Toxicol. 41: 398-403.

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

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

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

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

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

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

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

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

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

Chapman, G.A., et al. Manuscript. Effects of water hardness on the toxicity of metals to *Daphnia magna*. U.S. EPA, Corvallis, Oregon.

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

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

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

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

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

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

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

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

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

Chou, C.L., J.F. Uthe, J.D. Castell and J.C. Kean. 1987. Effect of dietary cadmium on growth, survival, and tissue concentrations of cadmium, zinc,

copper, and silver in juvenile american lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. 44: 1443-1450.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Department of the Environment. 1973. Water Pollution Research 1972. London. p. 37.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Gottofrey, J., I. Bjorklund and H. Tjalve. 1986. Effect of sodium isopropylxanthate, potassium amylxanthate and sodium diethyldithiocarbamate or

the uptake and distribution of cadmium in the brown trout (*Salmo trutta*). Aquat. Toxicol. 12: 171-184.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Hader, D.P., M. Lebert, H. Tahedl and P. Richter. 1997. The Erlanger flagellate test (EFT): photosynthetic flagellates in biological dosimeters. J. Photochem. Photobiol, B: Biol. 40: 23-28.

Haines, T.A. and W.G. Brumaugh. 1994. Metal concentration in the gill, gastrointestinal tract, and carcass of white suckers (*Catostomus commersoni*) in relation to lake acidity. Water, Air, Soil Pollut. 73: 265-274.

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

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

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

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

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

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

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

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

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

Hansen, I.V., J.M. Weeks and M.H. Depledge. 1995 Accumulation of copper, zinc, cadmium and chromium by the marine sponge *Halichondria panicea* Pallas and the implications for biomonitoring. Mar. Pollut. Bull. 31(3-1): 133-138.

Hansten, C., M. Heino and K. Pynnonen. 1996. Viability of glochidia of *Anodonta anatina* (Unionidae) exposed to selected metals and chelating agents. Aquat. Toxicol. 34: 1-12.

Hardy, J.K. and D.H. O'Keeffe. 1985. Cadmium uptake by the water hyacinth: effects of root mass, solution volume, complexers and other metal ions. Chemosphere. 14(5): 417-426.

Hardy, J.K. and N.B. Raber. 1985. Zinc uptake by the water hyacinth: effect of solution factors. Chemosphere. 14(9): 1155-1166.

Hare, L. 1992. Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity. Critic. Rev. Toxicol. 22(5/6): 327-369.

Hare, L, E. Saouter, P.G.C. Campbell, A. Tessier, F. Ribeyre and A. Boudou. 1991. Dynamics of cadmium, lead, and zinc exchange between nymphs of the burrowing mayfly *Hexagenia rigida* (Ephemeroptera) and the environment. Can. J. Fish. Aquat. Sci. 48: 39-47.

Hare, L., R. Carignan and MA. Huerta-Diaz. 1994. A field study of metal toxicity and accumulation by benthic invertebrates; implications for the acid-volatile sulfide (AVS) model. Limnol. Oceanogr. 39(7): 1653-1668.

Haritonidis, S., J.W. Rijstenbil, P. Malea, J. van Drie and J.A. Wijnholds. 1994. Trace metal interactions in the macroalga *Enteromorpha prolifera* (O.F. Muller) J. Ag., grown in water of the Scheldt estuary (Belgium and SW Netherlands), in response to cadmium exposure. BioMetals. 7: 61-66.

Harrison, S.E. and J.F. Klaverkamp. 1989. Uptake, elimination and tissue distribution of dietary and aqueous cadmium by rainbow trout (*Salmo gairdneri* Richardson) and lake whitefish (*Coregonus clupeaformis* Mitchell). Environmental Toxicology and Chemistry. 8: 87-97.

Hart, B.A. and B.D. Schaife. 1977. Toxicity and bioaccumulation of cadmium in *Chlorella pyrenoidosa*. Environ. Res. 14: 401.

Hartwell, S.I. 1997. Demonstration of a toxicological risk ranking method to correlate measures of ambient toxicity and fish community diversity. Environ. Toxicol. Chem. 16(2): 361-371.

Harvey, R.W. and S.N. Luoma. 1985. Separation of solute and particulate vectors of heavy metal uptake in controlled suspension-feeding experiments with *Macoma balthica*. Hydrobiologia. 21: 97-102.

Hashim, M.A., K.H. Chu, S.M. Phang and G.S. Ong. 1997. Adsorption equilibria of cadmium on algal biomass. Adsorpt. Sci. Technol. 15(6): 445-453.

Hatakeyama, S. 1987. Chronic effects of Cd on reproduction of *Polypedilum nubifer* (chironomidae) through water and food. Environ. Pollut. 48: 249-261.

Hatakeyama, S. and M. Yasuno. 1981a. The effects of cadmium-accumulated chlorella on the reproduction of *Moina macrocopa* (Cladocera). Ecotoxicol. Environ. Safety 5: 341.

Hatakeyama, S. and M. Yasuno. 1981b. Effects of cadmium on the periodicity of parturation and brook size of *Moina macrocopa* (Cladocera). Environ. Pollut. (Series A) 26: 111.

Haynes, G.J., A.J. Stewart and B.C. Harvey. 1989. Gender-dependent problems in toxicity tests with *Ceriodaphnia dubia*. Bull. Environ. Contam Toxicol. 43: 271-279.

Hazen, R.E. and T.J. Kneip. 1980. Biogeochemical cycling of cadmium in a marsh ecosystem. In: J.O. Nriagu (ed.), Cadmium in the Environment, Part I. Wiley, New York. p. 399.

Heinis, F., K.R. Timmermans and W.R. Swain. 1990. Short-term sublethal effects of cadmium on the filter feeding chironomid larva *Glyptotendipes pallens* (Meigen) (Diptera). Aquatic Toxicology. 16: 73-86.

Hendriks, J.A. 1995. Modelling equilibrium concentrations of microcontaminants in organisms of the Rhine delta: Can average field residues in the aquatic foodchain be predicted from laboratory accumulation? Aquat. Toxicol. 31: 1-25.

Herkovits, J. and C.S. Perez-Coll. 1993. Stage-dependent susceptibility of *Bufo arenarum* embryos to cadmium. Bull. Environ. Contam. Toxicol. 50: 608-611.

Herkovits, J. and C.S. Perez-Coll. 1995. Increased resistance against cadmium toxicity by means of pretreatment with low cadmium-zinc concentrations in *Bufo arenarum* embryos. Biol. Trace Elem. Res. 49: 171-175.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1997. Susceptibility of early life stages of *Xenopus laevis* to cadmium. Environmental Toxicology and Chemistry. 16(2): 312-316.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1998. Cadmium uptake and bioaccumulation in *Xenopus laevis* embryos at different developmental stages. Ecotoxicology and Environmental Safety. 39: 21-26.

Herwig, H.J., F. Brands, E. Kruitwagen and D.I. Zandee. 1989. Bioaccumulation and histochemical localization of cadmium in *Dreissena polymorpha* exposed to cadmium chloride. Aquat. Toxicol. 15: 269-286.

Heumann, H.G. 1987. Effects of heavy metals on growth and ultrastructure of *Chara vulgaris*. Protoplasma. 136: 37-48.

Hickey, C.W. and W.H. Clements. 1998. Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams. Environ. Toxicol. Chem. 17(11): 2338-2346.

Hickey, C.W. and M.L. Martin. 1995. Relative sensitivity of five benthic invertebrate species to reference toxicants and resin-acid contaminated sediments. Environ. Toxicol. Chem. 14(8): 1401-1409.

Hickey, C.W. and D.S. Roper. 1992. Acute toxicity of cadmium to two species of infaunal marine amphipods (tube-dwelling and burrowing) from New Zealand. Bull. Environ. Contam. Toxicol. 49: 165-170.

Hickey, C.W. and M.L. Vickers. 1992. Comparison of the sensitivity to heavy metals and pentachlorophenol of the mayflies *Deleatidium* spp. and the cladoceran *Daphnia magna*. New Zealand Journal of Marine and Freshwater Research. 26: 87-93.

Hilmy, A.M., M.B. Shabana and A.Y. Daabees. 1985. Bioaccumulation of cadmium: toxicity in *Mugil cephalus*. Comp. Biochem. Physiol. 81(1): 139-143.

Hiraoka, Y. 1985. Acute toxicity of 14 different kinds of metals affecting medaka (*Oryzias latipes*) fry. Hiroshima J. Med. Sci. 34: 327-30.

Hockett, J. R and D.R. Mount. 1996. Use of metal chelating agents to differentiate among sources of acute aquatic toxicity. Environ. Toxicol. Chem. 15: 1687-1693.

Hofslagare, O., G. Samuelsson and S. Sjoberg. 1985. Cadmium effects on photosynthesis and nitrate assimilation in *Scenedesmus obliquus*. A potentiometric study in an open $CO_2$-system. Environ. Exp. Bot. 25(1): 75-82.

Hogstrand, C., L. Goran and C. Haux. 1991. The importance of metallothionein for the accumulation of copper, zinc and cadmium in environmentally exposed perch, *Perca fluviatilis*. Pharmacol. Toxicol. 68: 492-501.

Holcombe, G.W., et al. 1983. Toxicity of selected priority pollutants to various aquatic organisms. Ecotoxicol. Environ. Safety 7: 400.

Holcombe, G.W., et al. 1984. Methods for conducting snail (*Aplexa hypnorum*) embryo through adult exposures: effects of cadmium and reduced pH levels. Arch. Environ. Contam. Toxicol. 13: 627.

Hollibaugh, D.L., et al. 1980. A comparison of the acute toxicities of ten heavy metals to the plankton from Sasnick Inlet, B.C., Canada. Estuarine Coastal Mar. Sci. 10: 93.

Hollis, L, K. Burnison and R.C. Playle. 1996. Does the age of metal-dissolved organic carbon complexes influence binding of metals to fish gills? Aquat. Toxicol. 35: 253-264.

Hollis, L., L. Muench and R.C. Playle. 1997. Influence of dissolved organic matter on copper binding, and calcium on cadmium binding, by gills of rainbow trout. J. Fish Biol. 50: 703-720.

Hong, J.S. and D.J. Reish. 1987. Acute toxicity of cadmium to eight species of marine amphipod and isopod crustaceans from southern California. Bull. Environ. Contam. Toxicol. 39: 884-888.

Hooten, R.L. and R.S. Carr. 1997. Development and application of a marine sediment pore-water toxicity test using *Ulva fasciata* zoospores. Environ. Toxicol. Chem. 17(5): 932-940.

Hornstrom, E. 1990. Toxicity test with algae - a discussion on the batch method. Ecotoxicol. Environ. Safety. 20: 343-353.

Hu, S., C.H. Tang and M. Wu. 1996. Cadmium accumulation by several seaweeds. Sci. Total Environ. 187: 65-71.

Huebert, D.B. and J.M. Shay. 1991. The effect of cadmium and its interaction with external calcium in the submerged aquatic macrophyte *Lemna trisulca* L. Aquat. Toxicol. 20: 57-72.

Huebert, D.B. and J.M. Shay. 1992. Zinc toxicity and its interaction with cadmium in the submerged aquatic macrophyte *Lemna trisulca* L. Environ. Toxicol. Chem. 11: 715-720.

Huebert, D.B. and J.M. Shay. 1993. The response of Lemna trisulca L. To cadmium. Environ. Pollut. 80: 247-253.

Huebert, D.B., B.S. Dyck and J.M. Shay. 1993. The effect of EDTA on the assessment of Cu toxicity in the submerged aquatic macrophyte, *Lemna trisulca* L. Aquat. Toxicol. 24: 183-194.

Huebner, J.D. and K.S. Pynnonen. 1992. Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals. Can. J. Zool. 70: 2348-2355.

Hughes, G.M., et al. 1979. A morphometric study of effects of nickel, chromium and cadmium on the secondary lamellae of rainbow trout gills. Water Res. 13: 665.

Hughes, J.S. 1973. Acute toxicity to thirty chemicals to striped bass (*Morone saxatilis*). Western Assoc. State Game Fish Comm., Salt Lake City, Utah. July.

Hung, Y. 1982. Effects of temperature and chelating agents on cadmium uptake in the American oyster. Bull. Environ. Contam. Toxicol. 28: 546.

Husaini, Y., A.K. Singh and L.C. Rai. 1991. Cadmium toxicity to photosynthesis and associated electron transport system of *Nostoc linckia*. Bull. Environ. Contam. Toxicol. 46: 146-150.

Hutcheson, M.S. 1975. The effects of temperature and salinity on cadmium uptake by the blue crab, *Callinectes sapidus*. Chesapeake Sci. 15: 237.

Hutchinson, T.C. and H. Czyrska. 1972. Cadmium and zinc toxicity and synergism to floating aquatic plants. In: Water Pollution Research in Canada 1972. Proc. 7th Canadian Symp. Water Pollut. Res., Inst. Environ. Sci. Eng. Publ. No. EI-3. p. 59.

Hutchinson, T.C. and P.M. Stokes. 1975. Heavy metal toxicity and algal bioassays. In: S. Barabos (ed.), Water Quality Parameters. ASTM STP 573. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 320.

Hutchinson, T.H., T.D. Williams and G.J. Eales. 1994. Toxicity of cadmium, hexavalent chromium and copper to marine fish larvae (*Cyprinodon variegatus*) and copepods (*Tisbe battagliai*). Marine Environmental Research. 38: 275-290.

Hutton, M. 1983. Sources of cadmium in the environment. Ecotoxicol. Environ. Saf. 7: 9-24.

Hwang, P.P., S.W. Lin and H.C. Lin. 1995. Different sensitivities to cadmium in Tilapia larvae (*Oreochromis mossambicus*; Teleostei). Arch. Environ. Contam. Toxicol. 29:1-7.

Hylland, K., M. Skold, J.S. Gunnarsson and J. Skei. 1997. Interactions between eutrophication and contaminants. IV. Effects on sediment-dwelling organisms. Mar. Pollut. Bull. 33(1-6): 90-99

Iftode, F, J.J. Curgy, A. Fleury and G. Fryd-Versavel. 1985. Action of a heavy ion, Cd2+, and the antagonistic effect of Ca2+, on two ciliates *Tetrahymena pyriformis* and *Euplotes vannus*. Acta Protozool. 24(3-4): 273-279.

Ikuta, K. 1987. Cadmium accumulation by a top shell *Batillus cornutus*. Nippon Suisan Gakkaishi. 53(7): 1237-1242.

Ilangovan, K., R.O. Canizares-Villanueva, S. Gonzalez Moreno and D. Voltolina. 1998. Effect of cadmium and zinc on respiration and photosynthesis in suspended and immobilized cultures of *Chlorella vulgaris* and *Scenedesmus acutus*. Bull. Environ. Contam. Toxicol. 60: 936-943.

Ingersoll, C.G. and N. Kemble. 2000. Unpublished. Methods development for long-term sediment toxicity tests with the amphipod *Hyalella azteca* and the midge *Chironomus tentans*.

Ingersoll, C.G. and R.W. Winner. 1982. Effect on *Daphnia pulex* (De Geer) of daily pulse exposures to copper or cadmium. Environ. Toxicol. Chem. 1: 321.

Inza, B., F. Ribeyre and A. Boudou. 1998. Dynamics of cadmium and mercury compounds (inorganic mercury or methylmercury): uptake and depuration in

*Corbicula fluminea*. Effects of temperature and pH. Aquat. Toxicol. 43: 273-285.

Irato, P. and Piccinni, E. 1996. Effects of cadmium and copper on *Astasia longa*: metal uptake and glutathione levels. Acta Protozool. 35: 281-285.

Issa, A.A., R. Abdel-Basset and M.S. Adam. 1995. Abolition of heavy metal toxicity on *Kirchneriella lunaris* (Chlorophyta) by calcium. Ann. Bot. 75: 189-192.

Jak, R.G., J.L. Maas and M.C.Th. Scholten. 1996. Evaluation of laboratory derived toxic effect concentrations of a mixture of metals by testing fresh water plankton communities in enclosure. Water Res. 30(5): 1215-1227.

Jana, S. and S.S. Sahana. 1988. Effects of copper, cadmium and chromium cations on the freshwater fish *Clarias batrachus* L. Physiol. Bohemoslov. 37(1): 79-82.

Jana, S. and S.S. Sahana. 1989. Sensitivity of the freshwater fishes *Clarias batrachus* and *Anabas testudineus* to heavy metals. Environ. Ecol. 7(2): 265-270.

Janssen, C.R. and G. Persoone. 1993. Rapid toxicity screening tests for aquatic biota. I. Methodology and experiments with *Daphnia magna*. Environ. Toxicol. Chem. 12:711-717.

Janssen, H.H. and N. Scholz. 1979. Uptake and cellular distribution of cadmium in *Mytilus edulis*. Mar. Biol. 55: 133.

Janssen, M.P.M., C. Oosterhoff, G.J.S.M. Heijmans, H. Van der Voet. 1995. The toxicity of metal salts and the population growth of the Ciliate *Colpoda cucculus*. Bull. Environ. Contam. Toxicol. 54: 597-605.

Janssens de Bisthoven, L.G., K.R. Timmerans and F. Ollevier. 1992. The concentration of cadmium, lead, copper and zinc in *Chironomus* gr. *thummi* larvae (Diptera, chironomidae) with deformed versus normal menta. Hydrobiol. 239: 141-149.

Jaworska, M, A. Gorczyca, J. Sepiol and P. Tomasik. 1997. Effect of metal ions on the *entomopathogenic nematode Heterorhabditis bacteriophora poinar*

(*Nematoda: Heterohabditidae*) under laboratory conditions. Water, Air, Soil Pollut. 93: 157-166.

Jenkins, K.D. and A.Z. Mason. 1988. Relationships between subcellular distributions of cadmium and perturbations in reproduction in the polychaete *Neanthes arenaceodentata*. Aquat. Toxicol. 12: 229-244.

Jenkins, K.D. and B.M. Sanders. 1986. Relationships between free cadmium ion activity in seawater, cadmium accumulation and subcellular distibution, and growth in polychaetes. Environ. Health Perspect. 65: 205-210.

Jenner, H.A. and J.P.M. Janssen-mommen. 1993. Duckweed *Lemna minor* as a tool for testing toxicity of coal residues and polluted sediments. Arch. Environ. Contam. Toxicol. 25: 3-11.

Jennings, J.R. and P.S. Rainbow. 1979a. Studies on the uptake of cadmium by the crab *Carcinus maenas* in the laboratory. I. Accumulation from seawater and a food source. Mar. Biol. 50: 131.

Jennings, J.R. and P.S. Rainbow. 1979b. Accumulation of cadmium by *Dunaliella tertiolecta* Butcher. Jour. Plankton Res. 1: 67.

Jindal, R. and A. Verma. 1990. Heavy metal toxicity to *Daphnia pulex*. Indian J. Environ. Hlth. 32(3): 289-292.

John, J., E.T. Gjessing, M. Grande and B. Salbu. 1987. Influence of aquatic humus and pH on the uptake and depuration of cadmium by the atlantic salmon (*Salmo salar* L.). Sci. Total Environ. 62: 253-265.

Johns, D.M. and D.C. Miller. 1982. The use of bioenergetics to investigate the mechanisms of pollutant toxicity in crustacean larvae. In: W.B. Vernberg, et al. (eds.), Physiological Mechanisms of Marine Pollutant Toxicity. Academic Press, New York. p. 261.

Johnson, M. and J. Gentile. 1979. Acute toxicity of cadmium, copper, and mercury to larval American lobster (*Homarus americanus*). Bull. Environ. Contam. Toxicol. 22: 258.

Jones, M.B. 1975. Synergistic effects of salinity, temperature and heavy metals on mortality and osmoregulation in marine and estuarine isopods (Crustacea). Mar. Biol. 30: 13.

Jonnalagadda, S.B. and P.V.V.P. Rao. 1993. Toxicity, bioavailability and metal speciation. Comp. Biochem. Physiol. 106C(3): 585-595.

Jop, K.M. 1991. Concentration of metals in various larval stages of four *Ephemeroptera* species. Bull. Environ. Contam. Toxicol. 46: 901-905.

Jop, K.M., A.M. Askew and R.B. Foster. 1995. Development of a water-effect ratio for copper, cadmium, and lead for the Great Works River in Maine using *Ceriodaphnia dubia* and *Salvelinus fontinalis*. Bull. Environ. Contam. Toxicol. 54: 29-33.

Juchelka, C.M. and T.W. Snell. 1994. Rapid toxicity assessment using rotifer ingestion rate. Arch. Environ. Contam. Toxicol. 26: 549-554.

Jude, D.J. 1973. Sublethal effects of ammonia and cadmium on growth of green sunfish. Ph.D. Thesis. Michigan State University.

Kaplan, D, Y.M. Heimer, A Abeliovich, P.B. Goldsbrough. 1995. Cadmium toxicity and resistance in *Chlorella* sp. Plant Sci. 109: 129-137.

Karlsson-Norrgren, L. And P. Runn. 1985. Cadmium dynamics in fish: pulse studies with $^{109}$Cd in female zebrafish, Brachydanio rerio. J. Fish Biol. 27: 571-581.

Kapur, K. and N.A. Yadav. 1982. The effects of certain heavy metal salts on the development of eggs in common carp, *Cyprinus carpio* var. *communis*. Acta Hydrochim. Hydrobiol. 10: 517.

Karez, C.S., S. Bonotto and S. Puiseux-Dao. 1989. Response of the unicellular giant alga *Acetabularia acetabulum* to cadmium toxicity and accumulation. Toxicological and Environmental Chemistry. 19: 223-232.

Kasuga, S. 1980. Sexual Differences of medaka, *Oryzias latipes* in the acute toxicity test of cadmium. Bull. Jap. Soc. Sci. Fish. 46(9): 1073-1076.

Katti, S.R. and A.G. Sathyanesan. 1985. Chronic effects of lead and cadmium on the testis of the catfish *Clarias batrachus*. Environ. Ecol. 3(4): 596-598.

Kay, J., D.G. Thomas, M.W. Brown, A. Cryer, D. Shurben, J.F. deL.G. Solbe and J.S. Garvey. 1986. Cadmium accumulation and protein binding patterns in tissues of the rainbow trout, *Salmo gairdneri*. Environ. Health Perspect. 65: 133-139.

Keduo, C. L. Yumei and H. Lanying. 1987. Effects os six heavy metals on hatching eggs and survival of larval of marine fish. Oceanol. Limol. Sin. (Haiyang Yu Huzhao). 18(2): 138-144.

Keenan, S. and M.A. Alikhan. 1991. Comparative study of cadmium and lead accumulations in *Cambarus bartoni* (Fab.) (Decapoda, crustacea) from an acidic and a neutral lake. Bull. Environ. Contam. Toxicol. 47: 91-96.

Keller, A.E. and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environ. Toxicol. Chem. 10: 539-546.

Kelly, M.G. and B.A. Whitton. 1989. Interspecific differences in Zn, Cd and Pb accumulation by freshwater algae and bryophytes. Hydrobiol. 17: 1-11.

Kerfoot, W.B. and S.A. Jacobs. 1976. Cadmium accrual in combined waste-treatment aquaculture system. Environ. Sci. Technol. 10: 662.

Kessler, E. 1985. An extremely cadmium-sensitive strain of *Chlorella*. Experientia. 41: 1621.

Kessler, E. 1986. Limits of growth of five *Chlorella* species in the presence of toxic heavy metals. Arch. Hydrobiol. 71(1): 123-128.

Kettle, W.D. and F. deNoyelles, Jr. 1986. Effects of cadmium stress on the plankton communities of experimental ponds. Journal of Freshwater Ecology. 3(4): 433-443.

Khan, A.T. and J.S. Weis. 1993. Bioaccumulation of heavy metals in two populations of mummichog (*Fundulus heteroclitus*). Bull. Environ. Contam. Toxicol. 51: 1-5.

Khan, A.T., J.S. Weis and L. D'Andrea. 1988. Studies of cadmium tolerance in two populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 40: 30-34.

Khan, A.T., J.S. Weis and L. D'Andrea. 1989. Bioaccumulation of four heavy metals in tow populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 42: 339-343.

Khan, A.T., J. Barbieri, S. Khan and F. Sweeney. 1992. A new short-term mysid toxicity test using sexual maturity as an endpoint. Aquatic Toxicology. 23: 97-105.

Khangarot, B.S. 1991. Toxicity of metals to a freshwater tubificid worm, *Tubifex tubifex* (Muller). Bull. Environ. Contam. Toxicol. 46: 906-912.

Khangarot, B.S. and P.K. Ray. 1987a. Correlation between heavy metal acute toxicity values in *Daphnia magna* and fish. Bull. Environ. Contam. Toxicol. 38: 722-726.

Khangarot, B.S. and P.K. Ray. 1987b. Sensitivity of toad tadpoles, *Bufo melanostictus* (Schneider), to heavy metals. Bull. Environ. Contam. Toxicol. 38(3): 523-527.

Khangarot, B.S. and P.K. Ray. 1989a. Investigation of correlation between physicochemical properties of metals and their toxicity to the water flea *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 18: 109-120.

Khangarot, B.S. and P.K. Ray. 1989b. Sensitivity of midge larvae of *Chironomus tentans* Fabricius (diptera chironomidea) to heavy metals. Bull. Environ. Contam. Toxicol. 1989. 42: 325-330.

Khangarot, B.S., P.K. Ray and H. Chandra. 1987. *Daphnia magna* as a model to assess heavy metal toxicity: comparative assessment with mouse system. Acta Hydrochim. Hydrobiol. 15(4): 427-432.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1996. Cadmium uptake by unicellular green microalgae. Chem. Eng. J. 62: 81-88.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1997. Cell surface area as a major parameter in the uptake of cadmium by unicellular green microalgae. Chem. Eng. J. 65: 13-19.

Khristoforova, N.K., S.M. Gnezdilova and G.A. Vlasova. 1984. Effect of cadmium on gametogenesis and offspring of the sea urchin *Strongylocentrotus intermedius*. Mar. Ecol. Prog. Ser. 17: 9-14.

Kiffney, P.M. and W.H. Clements. 1996. Size-dependent response of macroinvertebrates to metals in experimental streams. Environ. Toxicol. Chem. 15(8): 1352-1356.

Klass, E., et al. 1974. The effect of cadmium on population growth of the green alga *Scenedesmus quadricauda*. Bull. Environ. Contam. Toxicol. 12: 442.

Klaverkamp, J.F. and D.A. Duncan.1987. Acclimation to cadmium toxicity by white suckers: cadmium binding capacity and metal distribution in gill and liver cytosol. Environ. Toxicol. Chem. 6: 275-289.

Klerks, P.J. and P.R. Bartholomew. 1991. Cadmium accumulation and detoxification in a Cd-resistant population of the oligochaete *Limnodrilus hoffmeisteri*. Aquat. Toxicol. 19: 97-112.

Klockner, K. 1979. Uptake and accumulation of cadmium by *Ophryotrocha diadema* (Polychaeta). Mar. Ecol. Progress Series 1: 71.

Kluttgen, B. and H.T. Ratte. 1994. Effects of different food doses on cadmium toxicity to *Daphnia magna*. Environ. Toxicol. Chem. 13(10): 1619-1627.

Kluytmand, J.H., D.I. Zandee and E.L. Enserink. Effects of cadmium on the reproduction of *Mytilus edulis* L. University of Utrecht, Department of Experimental Zoology, 8 Padualan, 3584 CH Utrecht, The Netherlands.

Kneip, T.J. and R.E. Hazen. 1979. Deposit and mobility of cadmium in marsh-cove ecosystem and the relation to cadmium concentration in biota. Environ. Health Perspect. 28: 67.

Kobayashi, N. 1971. Fertilized sea urchin eggs as an indicator material for marine pollution bioassay, preliminary experiments. Publ. Seto Mar. Biol. Lab. 18: 379.

Kock, G., R. Hofer and S. Wograth. 1995. Accumulation of trace metals (Cd, Pb, Cu, Zn) in arctic char (*Salvelinus alpinus*) from oligotrophic alpine lakes: relation to alkalinity. Can. J. Fish. Aquat. Sci. 52: 2367-2376.

Koelmans, A.A., F. Gillissen and L. Lijklema. 1996. Influence of salinity and mineralization on trace metal sorption to cyanobacteria in natural waters. Water Res. 30(4): 853-864.

Kohler, K. and H.U. Riisgard. 1982. Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*. Mar. Biol. 66: 53.

Koivisto, S., M. Arner and N. Kautsky. 1997. Does cadmium pollution change trophic interactions in rockpool food webs? Environmental Toxicology and Chemistry. 16(6): 1330-1336.

Kolok, A.S., E.P. Plaisance and A. Abdelghani. 1998. Individual variation in the swimming performance of fishes: an overlooked source of variation in toxicity studies. Environ. Toxicol. Chem. 17(2): 282-285.

Kooijman, S.A.L.M. and J.J.M. Bedaux. 1996. Analysis of toxicity tests on Daphnia survival and reproduction. Water Res. 30(7): 1711-1723.

Kosakowska, A., L. Falkowski and J. Lewandowska. 1988. Effect of amino acids on the toxicity of heavy metals to phytoplankton. Bull. Environ. Contam. Toxicol. 40: 532-538.

Koyama, J, R. Kuroshima and A. Ishimatsu. 1992. The seawater fish for evaluation of the toxicity of pollutants. Mizu Kankyo Gakkaishi. 15(11): 804-813.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1992a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. pp.139-143.

Kraak, M.H.S., D. Lavy, W.H.M. Peeters and C. Davids. 1992b Chronic ecotoxicity of copper and cadmium to the zebra mussel *Dreissena polymorpha*. Arch. Environ. Contam. Toxicol. 23: 363-369.

Kraak, M.H.S., H. Schoon, W.H.M. Peeters and N.M. Van Straalen. 1993a. Chronic ecotoxicity of mixtures of Cu, Zn, and Cd to the zebra mussel *Dreissena polymorpha*. Ecotoxicol. Environ. Safety. 25: 315-327.

Kraak, M.H.S., D. Lavy, M. Toussaint, H. Schoon, W.H.M. Peeters and C. Davids. 1993b. Toxicity of heavy metals to the zebra mussel (*Dreissena polymorpha*). *In*: T.F. Nalepa and D.W. Schloessen (eds.), zebra mussels - biology, impacts, and control, chapter 29, Lewis Publishers, Boca Raton. 8: 491-502.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1994a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. 84(2): 139-143.

Kraak, M.H.S., D. Lavy, H. Schoon, M. Toussaint, W.H.M. Peeters and N.M. Van Straalen. 1994b. Ecotoxicity of mixtures of metals to the zebra mussel *Dreissena polymorpha*. Environ. Toxicol. Chem. 13: 109-114.

Kraak, M.H.S., Y.A. Wink, S.C. Stuijfzand, M.C. Buckert-de Jong, C.J. de Groot, W. Admiraal. 1994c. Chronic ecotoxicity of Zn and Pb to the zebra mussel *Dreissena polymorpha*. Aquatic Toxicology. 30: 77-89.

Kraal, M.H., M.H.S. Kraak, C.J. De Groot and C. Davids. 1995. Uptake and tissue distribution of dietary and aqueous cadmium by carp (*Cyprinus carpio*). Ecotoxicol. Environ. Safety. 31: 179-183.

Krantzberg, G. 1989a. Accumulation of essential and nonessential metals by chironomid larvae in relation to physical and chemical properties of the elements. Can. J. Fish. Aquat. Sci. 46: 1755-1761.

Krantzberg, G. 1989b. Metal accumulation by chironomid larvae: the effects of age and body weight on metal body burdens. Hydrobiol. 188/189: 497-506.

Krantzberg, G. and P.M. Stokes. 1988. The importance of surface adsorption and pH in metal accumulation by chironomids. Environ. Toxicol. Chem. 7: 653-670.

Krantzberg, G. and P.M. Stokes. 1989. Metal regulation, tolerance, and body burdens in the larvae of the genus *Chironomus*. Can. J. Fish. Aquat. Sci. 46: 389-398.

Krassoi, F.R., M. Julli. 1994. Chemical batch as a factor affecting the acute toxicity of the reference toxicant potassium dichromate to the cladoceran *Moina australiensis* (Sars). Bull. Environ. Contam. Toxicol. 53: 153-157.

Krawczynska, W., N.N. Pivovarova and A. Sobota. 1989. Effects of cadmium on growth, ultrastructure and content of chemical elements in *Tetrahymena pyriformis* and *Acanthamoeba castellanii*. Acta Protozoologica. 28:(3-4): 245-252.

Krishnaja, A.P., M.S. Rege and A.G. Joshi. 1987. Toxic effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab *Scylla serrata*. Environ. Res. 21: 109-119.

Kuhn, R. and M. Pattard. 1990. Results of the harmful effects of water pollutants to green algae (*Scenedesmus subspicatus*) in the cell multiplication inhibition test. Water Res. 24(1): 31-38.

Kuhn, R., M. Pattard, K.D. Pernak and A. Winter. 1989. Results of the harmful effects of water pollutants to *Daphnia magna* in the 21 day reproduction test. Wat. Res. 23(4): 501-510.

Kumada, H., et al. 1973. Acute and chronic toxicity, uptake and retention of cadmium in freshwater organisms. Bull. Freshwater Fish. Res. Lab. 22: 157.

Kumada, H., et al. 1980. Accumulation and biological effects of cadmium in rainbow trout. Bull. Jap. Soc. Sci. Fish. 46: 97.

Kumar, M. 1991. Accumulation of Pb, Cd, and Zn in aquatic snails from four freshwater sites in Steuben County, Indiana. Bios. 62(1): 2-8.

Kuroshima, R. 1987. Cadmium accumulation and it effect on calcium metabolism in the girella *Girella punctata* during a long term exposure. Bull. Jpn. Soc. Sci. Fish. 53(3): 445-450.

Kuroshima, R. 1992. Cadmium accumulation in the mummichog, *Fundulus heteroclitus*, adapted to various salinities. Bull. Environ. Contam. Toxicol. 49: 680-685.

Kuroshima, R., S. Kimura. 1990. Changes in toxicity of Cd and its accumulation in girella and goby with their growth. Bull. Jpn. Soc. Sci. Fish. 56(3): 431-453.

Kuroshima, R., S. Kimura, K. Date and Y. Yamamoto. 1993. Kinetic analysis of cadmium toxicity to red sea bream, *Pagrus major*. Ecotoxicol. Environ. Safety. 25: 300-314.

Kwan, K.H.M. and S. Smith. 1991. Some aspects of the kinetics of cadmium and thallium uptake by fronds of *Lemna minor* L. New Phytologist. 117(1): 91-102.

Laegreid, M., et al. 1983. Seasonal variation of cadmium toxicity toward the alga *Selenastrum capricornutum* Printz in two lakes with different humus content. Environ. Sci. Technol. 17: 357.

Lagerwerff, J.V. and A.W. Specht. 1970. Contamination of roadside soil and vegetation with cadmium, nickel, lead and zinc. Environ. Sci. Technol. 4: 583-586.

Lalande, M. and B. Pinel-Alloul. 1986. Acute toxicity of cadmium, copper, mercury and zinc to *Tropocyclops Prasinus Mexicanus* (Cyclopoida, copepoda) from three Quebec lakes. Environmental Toxicology and Chemistry. 5:95-102.

Lam, P.K.S. 1996a. Effects of cadmium on the consumption and absorption rates of a tropical freshwater snail, *Radix plicatulus*. Chemosphere. 32(11): 2127-2132.

Lam, P.K.S. 1996b. Interpopulation differences in acute response of *Brotia hainanensis* (gastropoda, prosobranchia) to cadmium: genetic or environmental variance? Environ. Pollut. 94(1): 1-7.

Lam. P.K.S., K.N. Yu, K.P. Ng and M.W.K. Chong. 1997. Cadmium uptake and depuration in the soft tissues of *Brotia hainanensis* (gastropoda: prosobranchia: thiaridae): a dynamic model. Chemosphere. 35(11): 2449-2461.

Landner, L. and A. Jernelov. 1969. Cadmium in aquatic systems. Metals and Ecology Symposium. Bulletin No. 5. Ecology Research Committee, Stockholm, Sweden. p. 47.

Langston, W.J. and M. Zhou. 1987. Cadmium accumulation, distribution and metabolism in the gastropod *Littorina littorea*: the role of metal-binding proteins. J. Mar. Biol. Assoc. U.K. 67: 585-601.

Larsen, J. and B. Svensmark. 1991. Labile species of Pb, Zn and Cd determined by anodic stripping staircase voltammetry and their toxicity to *Tetrahymena*. Talanta. 38(9): 981-988.

Lasenby, D.C. and J. Van Duyn. 1992. Zinc and cadmium accumulation by the opossum shrimp *Mysis relicta*. Arch. Environ. Contam. Toxicol. 23: 179-183.

Lasheen, M.R., S.A. Shehata and G.H. Ali. 1990. Effect of cadmium, copper and chromium (VI) on the growth of nile water algae. Water, Air, and Soil Pollution. 50: 19-30.

Laube, V.M., et al. 1980. Strategies of response to copper, cadmium, and lead by a blue-green and a green alga. Can. Jour. Microbiol. 26: 1300.

Lawrence, S.G. and M.H. Holoka. 1987. Effects of low concentrations of cadmium on the crustacean zooplankton community of an artificially acidified lake. Can. J. Fish. Aquat. Sci. 44: 163-172.

Lawrence, S.G. and M.H. Holoka. 1991. Response of crustacean zooplankton impounded in situ to cadmium at low environmental concentrations. Verh. Internat. Verein. Limnol. 24: 2254-2259.

LeBlanc, G.A. 1984. Interspecies relationships in acute toxicity of chemicals to aquatic organisms. Environ. Toxicol. Chem. 3: 47-60.

Lee, B.G. and S.N. Luoma. 1998. Influence of microalgal biomass on absorption efficiency of Cd, Cr, and Zn by two bivalves from San Francisco Bay. Limnol. Oceanogr. 43(7): 1455-1466.

Lee, H.H. and C.H. Xu. 1984. Differential response of marine organisms to certain metal and agrichemical pollutants. Bull. Environ. Contam. Toxicol. 33: 460-467.

Lee, H.L., B. Lustigman, V. Schwinge, I.Y. Chiu and S. Hsu. 1992. Effects of mercury and cadmium on the growth of *Anacystis nidulans*. Bull. Environ. Contam. Toxicol. 49: 272-278.

Lee, J.G. 1995. Cadmium; a toxin and a nutrient for marine phytoplankton. Environ. Sci. pp.1.

Lee, R. and Y. Oshima. 1998. Effects of selected pesticides, metals and organometallics on development of blue crab (*Callinectes sapidus*) embryos. Mar. Environ. Res. 46(1-5): 479-482.

Lee, R.F., K. O'Malley and Y. Oshima. 1996. Effects of toxicants on developing oocytes and embryos of the blue crab, *Callinectes sapidus*. Marine Environmental Research. 42(1-4): 125-128.

Lee, S. III, E.J. Na, Y.O. Cho, B. Koopman and G. Bitton. 1997. Short-term toxicity test based on algal uptake by *Ceriodaphnia dubia*. Water Environment Research. 69(7): 1207-1210.

Leonhard, S.L., et al. 1980. Evaluation of the acute toxicity of the heavy metal cadmium to nymphs of the burrowing mayfly, *Hexagenia rigida*. In: J.F. Flannagan and K.E. Marshall (eds.), Advances in Ephemeroptera Biology. Plenum Publishing Corp., New York. p. 457.

Les, A. And R.W. Walter. 1984. Toxicity and binding of copper, zinc and cadmium by the blue-green alga, *Chroococcus paris*. Water, Air, Soil Pollut. 23: 129-130.

Lewis, P.A. and W.B. Horning II. 1991. Differences in acute toxicity test results of three reference toxicants on *Daphnia* at two temperatures. Environmental Toxicology and Chemistry. 10: 1351-1357.

Lewis, P.A. and C.I. Weber. 1985. A study of the reliability of *Daphnia* acute toxicity tests. Aquatic Toxicology and Hazard Assessment: Seventh Symposium. ASTM STP 854, R.D. Cardwell, R. Purdy and R.C. Bahner (eds.), American Society for Testing and Materials, Philadelphia. pp. 73-86.

Liao, I.C. and C.S. Hsieh. 1990. Toxicity of three heavy metals to *Macrobrachium rosenbergii*. *In*: Proc. of the 2nd Asian Fisheries Forum, April 17 - 22, 1989, Tokyo, Japan, Asian Fish. Soc., Manila, Philippines: 923-926.

Lin, H.C. and W.A. Dunson. 1993. The effect of salinity on the acute toxicity of cadmium to the tropical, estuarine, hermaphroditic fish, *Rivulus marmoratus*: a comparison of Cd, Cu, and Zn tolerance with *Fundulus heteroclitus*. Arch. Environ. Contam. Toxicol. 25: 41-47.

Lithner, G, K. Holm and H. Borg. 1995. Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden). Water, Air Soil Pollut. 85: 785-790.

Lomagin, A.G. and L.V. Ul'yanova. 1993. A new bioassay on water pollution using duckweed *Lemna minor* L. Sov. Plant Physiol./Fiziol. Rast. 49(2): 327.

Lorz, H.W., et al. 1978. Effects of several metals on smolting of coho salmon. EPA-600/3-78-090. National Technical Information Service, Springfield, Virginia.

Loumbourdis, N.S., P. Kyriakopoulou-Sklavounou and G. Zachariadis. 1999. Effects of cadmium exposure on bioaccumulation and larval growth in the frog *Rana ridibunda*. Environ. Pollut. 104: 429-433.

Lourdes, M. 1994. Survival and heavy metal accumulation of two *Oreochromis niloticus* (L.) Strains exposed to mixtures of zinc, cadmium and mercury. Sci. Total Environ. 148: 31-38.

Lourdes, M. and E.V. Aralar. 1993. Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercury on two strains of tilapia *Oreochromis niloticus* (L.). Bull. Environ. Contam. Toxicol. 50: 891-897.

Lucker, T., D. Busch and W. Wosniok. 1997. Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771). Limnol. 27(10: 91-101.

Lue-Kim, H., et al. 1980. Cadmium toxicity on synchronous populations of *Chlorella ellipsoidea*. Can. Jour. Biol. 58: 1780.

Lussier, S.M., W.S. Boothman, S. Poucher, D. Champlin and A. Helmstetten. 1999. Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms. Environ. Toxicol. Chem. 18(5): 889-898

Lussier, S.M., et al. Manuscript. Acute and chronic effects of heavy metals and cyanide on *Mysidopsis bahia* (Crustacea: Mysidacea). U.S. EPA, Narragansett, Rhode Island.

McCahon, C.P. and D. Pascoe. 1988a. Cadmium toxicity to the freshwater amphipod *Gammarus pulex* (L.) During the moult cycle. Freshwater Biol. 19: 197-203.

McCahon, C.P. and D. Pascoe. 1988b. Increased sensitivity to cadmium of the freshwater amphipod *Gammarus pulex* (L.) during the reproductive period. Aquat. Toxicol. 13: 183-194.

McCahon, C.P. and D. Pascoe. 1988c. Use of *Gammarus pulex* (L.) In safety evaluation tests: culture and selection of a sensitive life stage. Ecotoxicol. Environ. Safety. 15: 245-252.

McCahon, C.P. and D. Pascoe. 1991. Brief-exposure of first and fourth instar *Chironomus riparius* larvae to equivalent assumed doses of cadmium: effects on adult emergence. Water, Air, and Soil Pollution. 60: 395-403.

McCahon, C.P., A.F. Brown and D. Pascoe. 1988. The effect of the acanthocephalan *Pomphorhynchus laevis* (Muller 1776) on the acute toxicity of cadmium to its intermediate host, the amphipod *Gammarus pulex* (L.). Arch. Environ. Contam. Toxicol 17: 239-243.

McCahon, C.P., A.J. Whiles and D. Pascoe. 1989. The toxicity of cadmium to different larval instars of the trichopteran larvae *Agapetus fuscipes* Curtis and the importance of life cycle information to the design of toxicity tests. Hydrobiol. 185: 153-162.

McCarty, L.S. and A.H. Houston. 1976. Effects of exposure to sublethal levels of cadmium upon water-electrolyte status in the goldfish (*Carassius auratus*). Jour. Fish Biol. 9: 11.

McCarty, L.S., et al. 1978. Toxicity of cadmium to goldfish, *Carassius auratus*, in hard and soft water. Jour. Fish. Res. Board Can. 35: 35.

McClurg, T.P. 1984. Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*. Water SA 10: 40.

McGee, B.L., D.A. Wright and D.J. Fisher. 1998. Biotic factors modifying acute toxicity of aqueous cadmium to estuarine amphipod *Leptocheirus plumulosus*. Arch. Environ. Contam. Toxicol. 34: 34-40.

McLeese, D.W. and S. Ray. 1984. Uptake and excretion of cadmium, CdEDTA, and zinc by *Macoma balthica*. Bull. Environ. Contam. Toxicol. 32: 85.

McLeese, D.W. and S. Ray. 1986. Toxicity of $CdCl_2$, CdEDTA, $CuCl_2$, and CuEDTA to Marine Invertebrates. Bull. Environ. Contam. Toxicol. 36: 749-755.

McLeese, D.W., et al. 1981. Lack of excretion of cadmium from lobsters. Chemosphere 10: 775.

McNicol, R.E. and E. Scherer. 1993. Influence of cadmium pre-exposure on the preference-avoidance responses of Lake Whitefish (*Coregonus clupeaformis*) to cadmium. Arch. Environ. Contam. Toxicol. 25: 36-40.

McNulty, E.W., F.J. Dwyer, M.R. Ellersieck, E.I. Greer, C.G. Ingersoll and C.F. Rabeni. 1999. Evaluation of ability of reference toxicity tests to identify stress in laboratory populations of the amphipod *Hyalella azteca*. Environmental Toxicology and Chemistry. 18(3): 544-548.

Ma, M., Z. Tong, Z. Wang, W. Zhu. 1999. Acute toxicity bioassay using the freshwater luminescent bacterium *Vibrio-qinghaiensis sp.* Nov.-Q67. Bull. Environ. Contam. Toxicol. 62: 247-253.

Maas, R.P. 1978. A field study of the relationship between heavy metal concentrations in stream water and selected benthic macroinvertebrate species. PB 297284. National Technical Information Service, Springfield, Virginia.

Macdonald, C.R. and J.B. Sprague. 1998. Cadmium in marine invertebrates and arctic cod in the Canadian Arctic. Distibution and ecological implications. Mar. Ecol. Prog. Ser. 47: 17-30.

Macdonald, J.M., J.D. Shields and R.K. Zimmer-Faust. 1988. Acute toxicities of eleven metals to early life-history stages of the yellow crab *Cancer anthonyi*. Marine Biology. 98: 201-207.

Macfie, S.M., Y. Tarmohamed and P.M. Welbourn. 1994. Effects of cadmium, cobalt, copper, and nickel on growth of the green alga *Chlamydomonas reinhardtii*: the influences of the cell wall and pH. Arch. Environ. Contam. Toxicol. 27: 454-458.

MacInnes, J.R., et al. 1977. Long-term cadmium stress in the cunner *Tautogolabrus adspersus*. Fish. Bull. 75: 199.

Mackie, G.L. 1989. Tolerances of five benthic invertebrates to hydrogen ions and metals (Cd, Pb, Al). Arch. Environ. Contam. Toxicol. 18: 215-223.

Madoni, P., D. Davoli and G. Gorbi. 1994. Acute toxicity of lead, chromium, and other heavy metals to ciliates from activated sludge plants. Bull. Environ. Contam. Toxicol. 53: 420-425.

Maeda, S., M. Mizoguchi, A. Ohki and J. Inanaga. 1990. A bioaccumulation of zinc and cadmium in freshwater alga, Chlorella vulgaris. Part II. Association mode of the metals and cell tissue. Chemosphere. 21(8): 965-973.

Majewski, H.S. and M.A. Giles. 1984. Cardio vascular-respiratory responses of rainbow trout (*Salmo gairdneri*) during chronic exposure to sublethal concentrations of cadmium. Water Res. 15: 1211.

Malea, P. 1994. Uptake of cadmium and the effect on viability of leaf cells in the seagrass *Halophila stipulacea* (Forsk.) Aschers. Bot. Mar. 37: 67-73.

Malley, D.F. and P.S.S. Chang. 1991. Early observations on the zooplankton community of a precambrian shield lake receiving experimental additions of cadmium. Verh.-Int. Ver. Theor. Angew. Limnol. 24: 2248-2253.

Malley, D.F., P.S.S. Chang and R.H. Hesslein. 1989. Whole lake addition of cadmium-109: radiotracer accumulation in the mussel population in the first season. The Science of the Total Environment. 87/88: 397-417.

Maloney, J. 1996. Influence of organic enrichment on the partitioning and bioavailability of cadmium in a microcosm study. Mar. Ecol. Prog. Ser. 144: 147-161.

Mansour, G.M.M. 1993. Effects on fish of cadmium concentrations in water. Oceanologia. 34: 91.

Manz, W., M. Wagner, R. A. and D.H. Schleifer. In situ characterization of the microbial consortia active in two wastewater treatment plants. Water Res. 28(8): 1715-1732.

Maranhao, P., J.C. Marques and V.M.C. Madeira. 1999. Zinc and cadmium concentrations in soft tissues of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) after exposure to zinc and cadmium. Environ. Toxicol. Chem. 18(8): 1769-1771.

Mark, U. and J. Solbe. 1998. Analysis of the ecetoc aquatic toxicity (EAT) database V- the relevance of Daphnia magna as a representative test species. Chemosphere. 36(1): 155-166.

Markham, J.W., et al. 1980. Effects of cadmium on *Laminaria saccharina* in culture. Mar. Ecol. Progress Series 3: 31.

Markich, S.J. and R.A. Jeffree. 1994. Absorption of divalent trace metals as analogues of calcium by Australian freshwater bivalves: an explanation of how water hardness reduces metal toxicity. Aquat. Toxicol. 29: 257-290.

Marr, J.C.A., H.L. Bergman, J. Lipton and C. Hogstrand. 1995a. Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. Can J. Aquat. Sci. 52: 2016-2030.

Marr, J.C.A., H.L. Bergman, M. Parker, J. Lipton, D. Cacela, W. Erickson and G.R Phillips. 1995b. Relative sensitivity of brown and rainbow trout to pulsed exposures of an acutely lethal mixture of metals typical of the Clark Fork River, Montana. Can. J. Aquat. Sci. 52: 2005-2015.

Marshall, J.S. 1978a. Population dynamics of *Daphnia galeata mendotae* as modified by chronic cadmium stress. Jour. Fish. Res. Board Can. 35: 461.

Marshall, J.S. 1978b. Field verification of cadmium toxicity to laboratory *Daphnia* populations. Bull. Environ. Contam. Toxicol. 20: 387.

Marshall, J.S., et al. 1981. An in situ study of cadmium and mercury stress in the plankton community of lake 382, Experimental Lakes Area, northwestern Ontario. Can. Jour. Fish. Aquat. Sci. 38: 1209.

Marshall, J.S., et al. 1983. Bioaccumulation and effects of cadmium and zinc in a Lake Michigan plankton community. Can. Jour. Fish. Aquat. Sci. 40: 1469.

Martin, T.R. and D.M. Holdich. 1986. The acute lethal toxicity of heavy metals to peracarid crustaceans (with particular reference to fresh-water asellids and gammarids). Wat. Res. 20(9): 1137-1147.

Martin, M., et al. 1981. Toxicities of ten metals to *Crassostrea gigas* and *Mytilus edulis* embryos and *Cancer magister* larvae. Mar. Pollut. Bull. 12: 305.

Martinez, M., J. Del Ramo, A. Torreblanca, A. Pastor and J. Diaz-Mayans. 1996. Cadmium toxicity, accumulation and metallothionein induction in *Echinogammarus echinosetosus*. J. Environ. Sci. Health. A31(7): 1605-1617.

Masters, J.A., M.A. Lewis and D.H. Davidson. 1991. Validation of a four-day *Ceriodaphnia* toxicity test and statistical considerations in data analysis. Environmental Toxicology and Chemistry. 10: 47-55.

Mateo, P., F Fernandez-Pinas and I. Bonilla. 1994. $O_2$-induced inactivation of nitrogenase as a mechanism for the toxic action of $Cd^{2+}$ on *Nostoc* UAM 208. New Phytologist. 126(2): 267-272.

Mathew, P. and N.R. Menon. 1992. Toxic responses of bivalves to metal mixtures. Bull. Environ. Contam. Toxicol. 48: 185-193.

Meador, J.P. 1993. The effect of laboratory holding on the toxicity response of marine infaunal amphipods to cadmium and tributyltin. Exp. Mar. Biol. Ecol. 174: 227-242.

Melgar, M.J., M. Perez, M.A. Garcia, J. Alonso and B. Miguez. 1997. Accumulation profiles in rainbow trout (*Oncorhynchus mykiss*) after short-term exposure to cadmium. J. Environ. Sci. Health. A32(3): 621-631.

Mersch, J., E. Morhain and C. Mouvet. 1993. Laboratory accumulation and depuration of copper and cadmium in the freshwater mussel *Dreissena polymorpha* and the aquatic moss *Rhynchostegium riparioides*. Chemosphere. 27(8): 1475-1485.

Mersch, J., P. Wagner and J.C. Pihan. 1996. Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight. Environ. Toxicol. Chem. 15(6): 886-893.

Metayer, C., et al. 1982. Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (*Solea solea*) and flounder (*Platichthus flesus*): changes as a function of age and organotropism. Rev. Int. Oceanogr. Med. 66-67: 33.

Meteyer, M.J., D.A. Wright and F.D. Martin. 1988. Effect of cadmium on early developmental stages of the sheepshead minnow (*Cyprinodon variegatus*). Environ. Toxicol. Chem. 7:321-328.

Meyer, J.S. 1999. A mechanistic explanation for the 1n(LC50) vs 1n(hardness) adjustment equation for metals. Environ. Sci. Technol. 33: 908-912.

Michibata, H., S Sahara and M.K. Kojima. 1986. Effects of calcium and magnesium ions on the toxicity of cadmium to the egg of the teleost, *Oryzias latipes*. Environ. Res. 40: 110-114.

Michibata, H., Y. Nojima and M.K. Kojima. 1987. Stage sensitivity of eggs of the teleost *Oryzias latipes* to cadmium exposure. Environmental Research. 42: 321-327.

Middaugh, D.P. and J.M. Dean. 1977. Comparative sensitivity of eggs, larvae and adults of the estuarine teleosts, *Fundulus heteroclitus* and *Menidia menidia* to cadmium. Bull. Environ. Contam. Toxicol. 17: 645.

Middaugh, D.P. and G. Floyd. 1978. The effect of prehatch and posthatch exposure to cadmium on salinity tolerance of larval grass shrimp, *Palaemonetes pugio*. Estuaries 1: 123.

Middaugh, D.P., et al. 1975. The response of larval fish *Leiostomus xanthurus* to environmental stress following sublethal cadmium exposure. Contrib. Mar. Sci. 19.

Migliore, J. And M. De Nicola Giudici. 1988. Effect of heavy metals (Hg, Cd, Cu and Fe) on two species of crustacean isopods, *Asellus aquaticus* (L.) And *Proasellus coxalis* Dollf. Verh.-Int. Ver. Theor. Angew. Limnol. 23: 1655-1659.

Ministry of Technology. 1967. Water Pollution Research 1966. London. p. 50

Mirenda, R.J. 1986. Toxicity and accumulation of cadmium in the crayfish, *Orconectes virilis* (Hagen). Arch. Environ. Contam. Toxicol. 15: 401-407.

Mirkes, D.Z., et al. 1978. Effects of cadmium and mercury on the behavioral responses and development of *Eurypanopeus depressus* larvae. Mar. Biol. 47: 143.

Mizutani, A., E. Ifune, A. Zanella and C. Eriksen. 1991. Uptake of lead, cadmium and zinc by the fairy shrimp, *Branchinecta longiantenna* (crustacea: anostraca). Hydrobiol. 212: 145-149.

Moller, V., V.E. Forbes and M.H. Depledge. 1994. Influence of acclimation and exposure temperature on the acute toxicity of cadmium to the freshwater snail *Potamopyrgus antipodarum* (Hydrobiidae). Environ. Toxicol. Chem. 13(9): 1519-1524.

Moore, M.N. and A.R.D. Stebbing. 1976. The quantitative cytochemical effects of three metal ions on a lysosomal hydrolase of a hydroid. Jour. Mar. Biol. Assoc. U.K. 56: 995.

Moraitou-Apostolopoulou, M. and G. Verriopoulos. 1982. Individual and combined effects of three heavy metals, Cu, Cd and Cr for the marine copepod *Tisbe holothuriae*. Hydrobiologia 87: 83.

Moraitou-Apostolopoulou, M., et al. 1979. Effects of sublethal concentrations of cadmium pollution for two populations of *Acartis clausi* (Copepoda) living at two differently polluted areas. Bull. Environ. Contam. Toxicol. 23: 642.

Morgan, W.S.G. 1979. Fish locomotor behavior patterns as a monitoring tool. Jour. Water Pollut. Control Fed. 51: 580.

Mostafa, L.Y. and Z. Khalil. 1986. Uptake, release and incorporation of radio active cadmium and mercury by the fresh water alga *Phormidium fragile*. Isot. Rad. Res. 18(1): 57-62.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life-cycle cladoceran toxicity test. Environ. Toxicol. Chem. 3: 425.

Mount, D.R., A.K. Barth, T.D. Garrison, D.A. Barten and J.R. Hockett. 1994. Dietary and waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium, lead and zinc using a live diet. Environ. Toxicol. Chem. 13(12): 2031-2041.

Moza, U., S.S. De Solva and B.M. Mitchell. 1995. Effect of sub-lethal concentrations of cadmium on food intake, growth and digestibility in the gold fish, *Carassius auratus* L. J. Environ. Biol. 16(3): 253-264.

Muino, C.V., L. Ferrari and A. Salibian. 1990. Protective action of ions against cadmium toxicity to young *Bufo arenarum* tadpoles. Bull. Environ. Contam. Toxicol. 45: 313-319.

Muller, K.W. and H.D. Payer. 1979. The influence of pH on the cadmium-repressed growth of the alga *Coelostrum proboscideum*. Physiol. Plant. 45: 415.

Muller, K.W. and H.D. Payer. 1980. The influence of zinc and light conditions on the cadmium-repressed growth of the green alga *Coelostrum proboscideum*. Physiol. Plant. 50: 265.

Munger, C. and L. Hare. 1997. Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): implications for predicting Cd bioaccumulation in nature. Environ. Sci. Technol. 31: 891-895.

Munger, C., et al. 1999. Influence of exposure time on the distribution of cadmium within the cladoceran *Ceriodaphnia dubia*. Aquat. Toxicol. 44: 195-200.

Muramoto, S. 1980. Decrease in cadmium concentration in a Cd-contaminated fish by short-term exposure to EDTA. Bull. Environ. Contam. Toxicol. 25: 828.

Musko, I.B., W. Meinel, R. Krause and M. Barlas. 1990. The impact of Cd and different pH on the amphipod *Gammarus fossarum* Koch (Crustacea: amphipoda). Comp. Biochem. Physiol. 96C(1): 11-16.

Mwangi, S.M. and M.A. Alikhan. 1993. Cadmium and nickel uptake by tissues of *Cambarus bartoni* (astacidae, decapoda, crustacea): effects on copper and zinc stores. Water Res. 27(5): 921-927.

Nacci, D., E. Jackim and R. Walsh. 1986. Comparative evaluation of three rapid marine toxicity tests: sea urchin early embryo growth test, sea urchin sperm cell toxicity test and microtox. Environmental Toxicology and Chemistry. 5: 521-525.

Nagel, K. And J. Voigt. 1995. Impaired photosynthesis in a cadmium-tolerant *Chlamydomonas* mutant strain. Microbiol. Res. 150: 105-110.

Nakagawa, H. and S. Ishio. 1988. Aspects of accumulation of cadmium ion in the egg of medaka *Oryzias latipes*. Bull. Jpn. Soc. Sci. Fish. (JPN)(ENG ABS). 54(12): 2159-2164.

Nakagawa, H. and S. Ishio. 1989. Effects of water hardness on the toxicity and accumulation of cadmium in eggs and larvae of medaka *Oryzias latipes*. Bull. Jpn. Soc. Sci. Fish. (JPN)(ENG ABS). 55(2): 327-331.

Nakano, Y. 1980. Chloroplast replication in *Euglena gracilis* grown in cadmium ion containing media. Agric. Biol. Chem. 44: 2733.

Nakano, Y., et al. 1980. Morphological observation of *Euglena gracilis* grown in zinc-sufficient media containing cadmium ions. Agric. Biol. Chem. 44: 2305.

Nalecz-Jawecki, G. and J. Sawicki. 1998. Toxicity of inorganic compounds in the spirotox test: a miniaturized version of the *Spirostomum ambiguum* test. Arch. Environ. Contam. Toxicol. 34: 1-5.

Nalecz-Jawecki, G., K. Demkowicz-Dobrzanski and J. Sawicki. 1993. Protozoan *Spirostomum ambiguum* as a highly sensitive bioindicator for rapid and easy determination of water quality. The Science of the Total Environment. pp. 1227-1234.

Nalewajko, C. 1995. Effects of cadmium and metal-contaminated sediments on photosynthesis heterotrophy, and phosphate uptake in Mackenzie River delta phytoplankton. Chemosphere. 30(7): 1401-1414.

Naqvi, S.M. and R.D. Howell. 1993. Toxicity of cadmium and lead to juvenile red swamp crayfish, *Procambarus clarkii*, and effects on fecundity of adults. Bull. Environ. Contam. Toxicol. 51: 303-308.

Nassiri, Y., J. Wery, J.L. Mansot, T. Ginsburger-Vogel. 1997. Cadmium bioaccumulation in *Tetraselmis suecica*: and electron energy loss spectroscopy (EELS) study. Arch. Environ. Contam. Toxicol. 33: 156-161.

Nasu, Y., K. Hirabayashi and M. Kugimoto. 1988. The toxicity of some water pollutants for lemnaceae (duckweed) plant. Proc. ICMR Semin. 8: 485-491.

Nasu, Y., et al. 1983. Comparative studies on the absorption of cadmium and copper in *Lemna paucicostata*. Environ. Pollut. (Series A) 32: 201.

Naylor, C. E.J. Cox, M.C. Bradley and P. Calow. 1992. Effect of differing maternal food ration on susceptibility of *Daphnia magna* Straus neonates to toxic substances. Aquat. Toxicol. 24: 75-82.

Nebeker, A.V., M.A. Cairns, S.T. Onjukka and R.H. Titus. 1986a. Effect of age on sensitivity of *Daphnia magna* to cadmium, copper and cyanazine. Environ. Toxicol. Chem. 5: 527-530.

Nebeker, A.V., S.T. Onjukka, M.A. Cairns and D.F. Krawczyk. 1986b. Survival of *Daphnia magna* and *Hyalella azteca* in cadmium-spiked water and sediment. Environ. Toxicol. Chem. 5: 933-938.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1994. Effects of cadmium on limb regeneration in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 27: 318-322.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1995. Effects of cadmium on growth and bioaccumulation in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 29: 492-499.

Negilski, D.S. 1976. Acute toxicity of zinc, cadmium and chromium to the marine fishes, yellow-eye mullet (*Aldrichetta forsteri* C. and V.) and smallmouth hardy head (*Atherinasoma microstoma* Whitley). Aust. Jour. Mar. Freshwater Res. 27: 137.

Nelson, D.A., et al. 1976. Biological effects of heavy metals on juvenile bay scallops, *Argopenten irradians*, in short-term exposures. Bull. Environ. Contam. Toxicol. 16: 275.

Nelson, D.A., J.E. Miller and A. Calabrese. 1988. Effect of heavy metals on bay scallops, surf clams, and blue mussels in acute and long-term exposures. Arch. Environ. Contam. Toxicol. 17: 595-600.

Nelson, S.M. 1994. Observed field tolerance of caddisfly larvae (*Hesperophylax sp.* to fish metal concentrations and low pH. J. Freshwater Ecol. 9(2): 169-170.

Nelson, S.M. and R.A. Roline. 1998. Evaluation of the sensitivity of rapid toxicity tests relative to daphnid acute lethality tests. Bull. Environ. Contam. Toxicol. 60: 292-299.

Nendza, M., T. Herbst, C. Kussatz and A. Gies. 1997. Potential for secondary poisoning and biomagnification in marine organisms. Chemosphere. 35(9): 1875-1885.

Neter, J. and W. Wasserman. 1974. Applied Linear Statistical Models. Irwin, Inc., Homewood, Illinois.

Niederlehner, B. 1984. A comparison of techniques for estimating the hazard of chemicals in the aquatic environment. M.S. thesis. Virginia Polytechnic Institute and State University.

Niederlehner, B.R., et al. 1985. Laboratory test evaluating the effects of cadmium on freshwater protozoan communities. Environmental Toxicology and Chemistry. 4: 155-165.

Nimmo, D.R., et al. 1977a. *Mysidopsis bahia*: an estuarine species suitable for life-cycle toxicity tests to determine the effects of a pollutant. In: F.L. Mayer and J.L. Hamelink (eds.), Aquatic Toxicology and Hazard Evaluation. ASTM STP 634. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 109.

Nimmo, D.R., et al. 1977b. Effects of cadmium on the shrimps *Penaeus duorarum*, *Palaemonetes pugio*, and *Palaemonetes vulgaris*. In: F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 131.

Nir, R., A. Gasith and A.S. Perry. 1990. Cadmium uptake and toxicity to water hyacinth: effect of repeated exposures under controlled conditions. Bull. Environ. Contam. Toxicol. 44: 149-157.

Noel-Lambot, F., et al. 1980. Cadmium, zinc, and copper accumulation in limpets (*Patella vulgata*) from the British channel and special reference to metallothioneins. Mar. Ecol. Progress Series 2: 81.

Nolan, C.V. and E.J. Duke. 1983. Cadmium accumulation and toxicity in *Mytilus edulis*: involvement of metallothioneins and heavy molecular weight protein. Aquat. Toxicol. 4: 153.

Noraho, N. and J.P. Gaur. 1995. Effect of cations, including heavy metals, on cadmium uptake by *Lemna polyrhiza* L. BioMetals. 8: 95-98.

Norey, C.G., M.W. Brown, A. Cryer and J. Kay. 1990a. A comparison of the accumulation, tissue distribution and secretion of cadmium in different species of freshwater fish. Comp. Biochem. Physiol. 96C(1): 181-184.

Norey, C.G., A. Cryer and J. Kay. 1990b. Cadmium uptake and sequestration in the pike (*Esox lucius*) Comp. Biochem. Physiol. 95C(2): 217-221.

Notenboom, J., K. Cruys, J. Hoekstra and P. Van Beelen. 1992. Effect of ambient oxygen concentration upon the acute toxicity of chlorophenols and heavy metals to the groundwater copepod *Parastenocaris germanica* (crustacea). Ecotoxicol. Environ. Safe. 24: 131-143.

Nott, J.A. and A. Nicolaidou. 1994. Variable transfer of detoxified metals from snails to hermit crabs in marine food chains. Mar. Biol. 120: 369-377.

Nugegoda, D. and P.S. Rainbow. 1995. The uptake of dissolved zinc and cadmium by the decapod crustacean *Palaemon elegans*. Mar. Pollut. Bull. 31(4-12): 460-463.

O’Hara, J. 1973a. The influence of temperature and salinity on the toxicity of cadmium to the fiddler crab, *Uca pugilator*. Fish. Bull. 71: 149.

O’Hara, J. 1973b. Cadmium uptake by fiddler crabs exposed to temperature and salinity stress. Jour. Fish. Res. Board Can. 30: 846.

O'Neill, J.G. 1981. Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*. Bull. Environ. Contam. Toxicol. 27: 42.

Oakley, S.M., et al. 1983. Accumulation of cadmium by *Abarenicola pacifica*. Sci. Total Environ. 28: 105.

Odin, M., F. Ribeyre and A. Boudou. 1996. Temperature and pH effects on cadmium and methylmercury bioaccumulation by nymphs of the burrowing mayfly *Hexagenia rigida*, from water column or sediment source. Arch. Environ. Contam. Toxicol. 31: 339-349.

Odin, M., F. Ribeyre and A. Boudou. 1997. Depuration processes after exposure of burrowing mayfly nymphs (*Hexagenia rigida*) to methylmercury and cadmium from water column or sediment: effects of temperature and pH. Aquat. Toxicol. 37: 125-137.

Oikari, A., J. Kukkonen and V. Virtanen. 1992. Acute toxicity of chemicals to *Daphnia magna* in humic water. Sci. Total Environ. 117/118: 367-377.

Ojaveer, E., et al. 1980. On the effect of copper, cadmium and zinc on the embryonic development of Baltic spring spawning herring. Finnish Mar. Res. 247: 135.

Okamoto, O.K., C.S. Asano, E. Aidar and P. Colepicolo. 1996. Effects of cadmium on growth and superoxide dismutase activity of the marine microalga *Tetraselmis gracilis* (Prasinophyceae) J. Physiol. 32: 74-79.

Olesen, T.M.E. and J.M. Weeks. 1994. Accumulation of Cd by the marine sponge *Halichondria panicea* Pallas: effects upon filtration rate and its relevance for biomonitoring. Bull. Environ. Contam. Toxicol. 52: 722-728.

Onuoha, G.C., F.O. Nwadukwe and E.S. Erondu. 1996. Comparative toxicity of cadmium to crustacean zooplankton (copepods and ostracods) Environ. Ecol. 14(3); 557-562.

Oronsaye, J.A.O. 1989. Histological changes in the kidneys and gills of the stickleback, *Gasterosteus aculeatus* L, exposed to dissolved cadmium in hard water. Ecotoxicology and Environmental Safety. 17: 279-290.

Outridge, P.M. 1992. Comparing Cd toxicity tests with plants in monocultures and species mixtures. Bull. Environ. Contam. Toxicol. 48: 344-351.

Palackova, J., D. Pravda, K. Fasaic and O. Celechovska. 1994. Sublethal effects of cadmium on carp (*Cyprinus carpio*) fingerlings. In: R. Muller and R. Lloyd (eds.), Sublethal and chronic effects of pollutants on freshwater fish, chapter 5, Fishing News Books, London: 53-61.

Palawski, D., J.B. Hunn and F.J. Dwyer. 1985. Sensitivity of young striped bass to organic and inorganic contaminants in fresh and saline water. Trans. Am. Fish. Soc. 114: 748-753.

Pantani, C., G. Pannunzio, M. De Cristofaro, A.A. Novelli and M. Salvatori. 1997. Comparative acute toxicity of some pesticides, metals, and surfactants to *Gammarus italicus* Goedm. and *Echinogammarus tibaldii* Pink. and stock (crustacea: amphipoda). Bull. Environ. Contam. Toxicol. 59(6): 963-967.

Papathanassiou, E. 1983. Effects of cadmium and mercury ions on respiration and survival of the common prawn *Palaemon serratus* (pennant). Rev. Int. Oceanogr. Med. 72: 21-35.

Papathanassiou, E. 1986. Cadmium Accumulation and ultrastructural alterations in oogenesis of the prawn *Palaemon serratus* (pennant). Bull. Environ. Contam. Toxicol. 36: 192-198.

Papoutsoglou, S.E. and P.D. Abel. 1988. Sublethal toxicity and accumulation of cadmium in *Tilapia aurea*. Bull. Environ. Contam. Toxicol. 41: 404-411.

Papoutsoglou, S.E. and D. Abel. 1993. Studies on the lethal and sublethal effects of cadmium on some commercially cultured species of the Mediterranean. *In*: Final Reports on Projects (activity G), UNEP Mediterranean Action Plan, Athens, Greece. MAP Tech. Rep. Ser. No. 48: 33-43.

Pardue, W.J. and T.S. Wood. 1980. Baseline toxicity data for freshwater bryoza exposed to copper, cadmium, chromium, and zinc. Jour. Tennessee Acad. Sci. 55: 27.

Park, E.H., H.H. Chang, W.N. Joo, H.S. Chung and H.S. Kwak. 1994. Assessment of the estuarine hermaphroditic fish *Rivulus marmoratus* as a useful euryhaline

species for acute toxicity tests as shown using cadmium. Can. J. Fish. Aquat. Sci. 51: 280-285.

Parker, J.G. 1984. The effects of selected chemicals and water quality on the marine polychaete *Ophryotrocha diadema*. Water Res. 18: 865.

Pascoe, D. and P. Cram. 1977. The effect of parasitism on the toxicity of cadmium to the three-spined stickleback, *Gasterosteus aculeatus* L. Jour. Fish. Biol. 10: 467.

Pascoe, D. and D.L. Mattey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback *Gasterosteus aculeatus* L. Jour. Fish. Biol. 11: 207.

Pascoe, D. and N.A.M. Shazili. 1986. Episodic pollution - a comparison of brief and continuous exposure of rainbow trout to cadmium. Ecotoxicol. Environ. Safety. 12: 189-198.

Pascoe, D., S.A. Evans and J. Woodworth. 1986. Heavy metal toxicity to fish and the influence of water hardness. Arch. Environ. Contam. Toxicol. 15: 481-487.

Pascoe, D., K.A. Williams and D.W.J. Green. 1989. Chronic toxicity of cadmium to *Chironomus riparius* Meigen - effects upon larval development and adult emergence. Hydrobiologia. 175: 109-115.

Pascoe, D., A.F. Brown, B.M.J. Evans and C. McKavanagh. 1990. Effects and fate of cadmium during toxicity tests with *Chironomus riparius* - the influence of food and artificial sediment. Arch. Environ. Contam. Toxicol. 19: 872-877.

Pauli, W. and S. Berger. 1997. Toxicological comparisons of *Tetrahymena* species, end points and growth media: supplementary investigations to the pilot ring test. Chemosphere. 35(5): 1043-1052.

Pavicic, J., M. Skreblin, I. Kregar, M. Tusek-Znidaric and P. Stegnar. 1994. Embryo-larval tolerance of *Mytilus galloprovincialis*, exposed to the elevated sea water metal concentrations - I. Toxic effects of Cd, Zn and Hg in relation to the metallothionein level. Comp. Biochem. Physiol. 107C(2): 249-257.

Pawlik, B. and T. Skowronski. 1994. Transport and toxicity of cadmium: its regulation in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 34(2): 225-233.

Pawlik, B., T. Skowronski, Z. Ramazanow, P. Gardestrom and G. Samuelsson. 1993. pH-dependent cadmium transport inhibits photosynthesis in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 33(2): 331-337.

Pecon, J. and E.N. Powell. 1981. Effect of the amino acid histidine on the uptake of cadmium from the digestive system of the blue crab, *Callinectes sapidus*. Bull. Environ. Contam. Toxicol. 27: 34.

Pedersen, F. and G.I. Petersen. 1996. Variability of species sensitivity to complex mixtures. Water Sci. Tech. 33(6): 109-119.

Pelgrom, S.M.G.J., L.P.M. Lamers, J.A.M. Garritsen, B.M. Pels, R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1994. Interactions between copper and cadmium during single and combined exposure in juvenile tilapia *Oreochromis mossambicus*: influence of feeding condition on whole body metal accumulation and the effect of the metals on tissue water and ion content. Aquat. Toxicol. 30: 117-135.

Pelgrom, S.M.G.J., R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1997. Calcium fluxes in juvenile tilapia, *Oreochromis mossambicus*, exposed to sublethal waterborne Cd, Cu or mixtures of these metals. Environ. Toxicol Chem. 16(4): 770-774.

Pellegrini, M., An. Laugier, M. Sergent., R. Phan-Tan-Luu, R. Valls and L. Pellegrini. 1993. Interactions between the toxicity of the heavy metals cadmium, copper, zinc in combinations and the detoxifying role of calcium in the brown alga *Cystoseira barbata*. J. Appl. Phycol. 5: 351-361.

Pennington, C.H., et al. 1982. Contaminant levels in fishes from Brown’s Lake, Mississippi. Jour. Mississippi Acad. Sci. 27: 139.

Penttinen, S., J. Kukkonen and A. Oikari. 1995. The kinetics of cadmium in *Daphnia magna* as affected by humic substances and water hardness. Ecotoxicol. Environ. Safety. 30: 72-76.

Penttinen, S., A. Kostamo and J.V.K. Kukkonen. 1998. Combined effects of dissolved organic material and water hardness on toxicity of cadmium to *Daphnia magna*. Environ. Toxicol. Chem. 17(12): 2498-2503.

Pereira, J.J., R. Mercaldo-Allen, C. Kuropat, D. Luedke and G. Sennefelder. 1993. Effect of cadmium accumulation on serum vitellogenin levels and hepatosomatic and gonadosomatic indices of winter flounder (*Pleuronectes americanus*). Arch. Environ. Contam. Toxicol. 24: 427-431.

Perez-Coll, C.S. and J. Herkovits. 1996. Stage-dependent uptake of cadmium by *Bufo arenarum* embryos. Bull. Environ. Contam. Toxicol. 56: 663-669.

Pesch, G.G. and N.E. Stewart. 1980. Cadmium toxicity to three species of estuarine invertebrates. Mar. Environ. Res. 3: 145.

Pesonen, M. And T.B. Andersson. 1997. Fish primary hepatocyte culture; and important model for xenobiotic metabolism and toxicity studies. Aquat. Toxicol. 37: 253-267.

Peterson, H.G. 1991. Toxicity testing using a chemostat-grown green alga, *Selenastrum capricornutum*. In: J.W. Garoch, W.K. Lower, W. Wang and M.A. Lewis (eds.), Plants for toxic assessment, 2nd Volume, ASTM STP 1115, Philadelphia, PA: 107-117.

Peterson, H.G., F.P. Healey and R. Wagemann. 1984. Metal toxicity to algae: a highly pH dependent phenomenon. Can. J. Fish. Aquat. Sci. 41: 974-979.

Peterson, R.H., et al. 1983. Effects of cadmium on yolk utilization, growth, and survival of atlantic salmon alevins on newly feeding fry. Arch. Environ. Contam. Toxicol. 12: 37.

Peterson, R.H., J.L. Metcalfe and S. Ray. 1985. Uptake of cadmium by eggs and alevins of atlantic salmon (*Salmo salar*) as influenced by acidic conditions. Bull. Environ. Contam. Toxicol. 34: 359-368.

Phelps, H.L. 1979. Cadmium sorption in estuarine mud-type sediment and the accumulation of cadmium in the soft-shell clam, *Mya arenaria*. Estuaries 2: 40.

Phillips, D.J.H. 1976. The common mussel *Mytilus edulis* as an indicator of pollution by zinc, cadmium, lead and copper. I. effects of environmental variables on uptake of metals. Mar. Biol. 38: 59.

Phillips, G.R. and R.C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: a literature review. EPA-600/3-78-103. National Technical Information Service, Springfield, Virginia.

Phipps, G.L. and G.W. Holcombe. 1985. A method for aquatic multiple species toxicant testing: acute toxicity of 10 chemicals to 5 vertebrates and 2 invertebrates. Environmental Pollution (Series A). 38: 141-157.

Phipps, G.L., V.R. Mattson, G.T. Ankley. 1995. Relative sensitivity of three freshwater benthic macroinvertebrates to ten contaminants. Arch. Environ. Contam. Toxicol. 28: 281-286.

Pickering, Q.H. and M.H. Gast. 1972. Acute and chronic toxicity of cadmium to the fathead minnow (*Pimephales promelas*) Jour. Fish. Res. Board Can. 29: 1099.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. Jour. 10: 453.

Playle, R.C., D.G. Dixon and K. Burnison. 1993a. Copper and cadmium binding to fish gills: estimates of metal-gill stability constants and modelling of metal accumulation. Can. J. Fish. Aquat. Sci. 50: 2678-2687.

Playle, R.C., D.G. Dixon and K. Burnison. 1993b. Copper and cadmium binding to fish gills: modification by dissolved organic carbon and synthetic ligands. Can. J. Fish. Aquat. Sci. 50: 2667-2677.

Polar, E. And R. Kucukcezzar. 1986. Influence of some metal chelators and light regimes on bioaccumulation and toxicity of $Cd^{2+}$ in duckweed (*Lemna gibba*). Physiol. Plant 66: 87-93.

Poldoski, J.E. 1979. Cadmium bioaccumulation assays. Their relationship to various ionic equilibria in Lake Superior water. Environ. Sci. Technol. 13: 701.

Postma, J.F. and C. Davids. 1995. Tolerance induction and life cycle changes in cadmium-exposed *Chironomus riparius* (diptera) during consecutive generation. Ecotoxicol. Environ. Safety. 30: 195-202.

Postma, J.F., M.C. Buckert-de Jong, N. Staats and C. Davids. 1994. Chronic toxicity of cadmium to Chironomus reparius (diptera: chironomidae) at different food levels. Arch. Environ. Contam. Toxicol. 26: 143-148.

Postma. J.F., P. Van Nugteren and M.B. Buckert-De Jong. 1996. Increased cadmium excretion in metal-adapted populations of the midge *Chironomus riparius* (Diptera). Environ. Toxicol Chem. 15(3): 332-339.

Poulsen, E., et al. 1982. Accumulation of cadmium and bioenergetics in the mussel *Mytilus edulis*. Mar. Biol. 68: 25.

Poulton. B.C., D.P. Monda, D.F. Woodward, M.L.Wildhaber and W.G. Brumbaugh. 1995. Relations between benthic community structure and metals concentrations in aquatic macroinvertebrates: Clark Fork River, Montana. J. Freshwater Ecol. 10(3): 277-293.

Prasad, M.N.V., K. Drej, A. Skawinska and K. Stralka. 1998. Toxicity of cadmium and copper in *Chlamydomonas reinhardtii* wild-type (WT2137) and cell wall deficient mutant strain (CW15). Bull. Environ. Contam. Toxicol. 60: 306-311.

Presing, M., K.V. Balogh and J. Salanki. 1993. Cadmium uptake and depuration in different organs of *Lymnaea stagnalis* L. And the effect of cadmium on the natural zinc level. Arch. Environ. Contam. Toxicol. 24: 28-34.

Prevot, P. and M.O. Soyer-Gobillard. 1986. Combined action of cadmium and selenium on two marine dinoflagellates in culture, *Prorocentrum micans* Ehrbg. and *Crypthecodinium cohnii* Biecheler. J. Protozool. 33(1): 42-47.

Pringle, B.H., et al. 1968. Trace metal accumulation by estuarine mollusks. Am. Soc. Civil Eng., Jour. Sanit. Eng. Div. 94: 455.

Pynnonen, K. 1995. Effect of pH, hardness and maternal pre-exposure on the toxicity of Cd, Cu and Zn to the glochidial larvae of a freshwater clam *Anodonta cygnea*. Water Res. 29(1): 247-254.

Qichen, C., Z. Kejien and Z. Guanwen. 1988. A comprehensive investigation of the toxic effects of heavy metals on fish. J. Fish. China/Shuichan Xuebao (Chi.) (Eng. Trans.) (Author communication used). 12(1): 21-33.

Qureshi, S.A., et al. 1980. Acute toxicity of four heavy metals to benthic fish food organisms from the river Khan, Ujjain. Int. Jour. Environ. Studies 15: 59.

Rachlin, J.W. and A. Grosso. 1991. The effects of pH on the growth of *Chlorella vulgaris* and its interactions with cadmium toxicity. Arch. Environ. Contam. Toxicol. 20: 505-508.

Rachlin, J.W. and A. Grosso. 1993. The growth response of the green alga *Chlorella vulgaris* to combined divalent cation exposure. Arch. Environ. Contam. Toxicol. 24:16-20.

Rachlin, J.W., et al. 1982. The growth responses of *Chlorella saccharophila*, *Navicula incerta* and *Nitzschia closterium* to selected concentrations of cadmium. Bull. Torrey Bot. Club 109: 129.

Rachlin, J.W., et al. 1984. The toxicological response of the algae *Anabaena flos-aquae* (Cyanophyceae) to cadmium. Arch. Environ. Contam. Toxicol. 13: 143.

Radetski, C.M., J.F. Ferard and C. Blaise. 1995. A semistatic microplate-based phytotoxicity test. Environmental Toxicology and Chemistry. 14(2): 299-302.

Radix, P., M. Leonard, C. Papantoniou, G. Roman, E. Saouter, S. Gallotti-Schmitt, H. Threbaud and P. Vasseur. 1999. Comparison of *Brachionus calyciflorus* 2-D and microtox® chronic 22-h tests with *Daphnia magna* 21-D test for chronic toxicity assessment of chemicals. Environ. Toxicol. Chem. 18(10): 2178-2185.

Rai, U.N., R.D. Tripathi, S. Sinha and P. Chandra. 1995. Chromium and cadmium bioaccumulation and toxicity in *Hydrilla verticillata* (l.f.) Royle and *Chara corallina* Wildenow. J. Environ. Sci. Health. A30: 537-551.

Rainbow, P.S. 1985. Accumulation of Zn, Cu and Cd by crabs and barnacles. Estuarine Coastal Shelf Sci. 21: 669-686.

Rainbow, P.S. and M.K.H Kwan. 1995. Physiological responses and the uptake of cadmium and zinc by the amphipod crustacean *Orchestia gammarellus*. Mar. Ecol. Prog. Ser. 127: 87-102.

Rainbow, P.S. and S.L. White. 1989. Comparative strategies of heavy metal accumulation by crustaceans: zinc, copper and cadmium in a decapod, and amphipod and a barnacle. Hydrobiol. 174: 245-262.

Rainbow, P.S., et al. 1980. Effects of chelating agents on the accumulation of cadmium by the barnacle *Semibalanus balanoides*, and the complexation of soluble Cd, Zn and Cu. Mar. Ecol. Progress Series 2: 143.

Ralph, P.J. and M.D. Burchett. 1998. Photosynthetic response of *Halophila ovalis* to heavy metal stress. Environ. Pollut. 103: 91-101.

Ramachandran, S., T.R. Patel and M.H. Colbo. 1997. Effect of copper and cadmium on three Malaysian tropical estuarine invertebrate larvae. Ecotoxicol. Environ. Safety. 36: 183-188.

Ramamoorthy, S. and K. Blumhagen. 1984. Uptake of Zn, Cd, and Hg by fish in the presence of competing compartments. Can. Jour. Fish. Aquat. Sci. 41: 750.

Ramesha, A.M., T.R.C. Guptha, R.J. Katti, G. Gowda and C. Lingdhal. 1996. Toxicity of cadmium to common carp *Cyprinus carpio* (Linn.). Environ. Ecol. 14(2): 329-333.

Ramesha, A.M., T.R.C. Gupta, C. Lingdhal, K.V.B. Kumar, G. Gowda and K.S. Udupa. 1997. Combined toxicity of mercury and cadmium to the common carp *Cyprinus carpio* (Linn.) Environ. Ecol. 15(1): 194-198.

Ramirez, P., G. Barrera and C. Rosas. 1989. Effects of chromium and cadmium upon respiration and survival of *Callinectes similis*. Bull. Environ. Contam. Toxicol. 43: 850-857.

Rao, J.I. and M.N. Madhyastha. 1987. Toxicities of some heavy metals to the tadpoles of frog, *Microhyla ornata* (Dumeril and Bibron). Toxicol. Lett. 36: 205-208.

Ray, S., et al. 1981. Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates - a laboratory study. Bull. Environ. Contam. Toxicol. 25: 315.

Rayms-Keller, A., K.E. Olson, M. McGaw, C. Oray, J.O. Carlson and B.J. Beaty. 1998. Effect of heavy metals on *Aedes aegypti* (diptera: culicidae) larvae. Ecotoxicol. Environ. Safety. 39: 41-17.

Reader, J.P., N.C. Everall, M.D.J. Sayer and R. Morris. 1989. The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L. J. Fish Biol. 35: 187-198.

Rebhun, S. and A. Ben-Amotz. 1984. The distribution of cadmium between the marine alga *Chlorella stigmatophora* and sea water medium. Water Res. 18(2): 173-179.

Rebhun, S. and A. Ben-Amotz. 1986. Effect of NaCl concentration on cadmium uptake by the halophilic alga *Dunaliella salina*. Mar. Ecol. Prog. Ser. 30: 215-219.

Rebhun, S. and A. Ben-Amotz. 1988. Antagonistic effect of maganese to cadmium toxicity in the alga *Dunaliella salina*. Mar. Ecol. Prog Ser. 42: 97-104.

Reddy, P.S. and M. Fingerman. 1994. Effect of cadmium chloride on amylase activity in the red swamp crayfish, *Procambarus clarkii*. Comp. Biochem. Physiol. 109C(3): 309-314.

Reddy, P.S., S.R. Tuberty and M. Fingerman. 1997. Effects of cadmium and mercury on ovarian maturation in the red swamp crayfish, *Procambarus clarkii*. Ecotoxicol. Environ. Safety. 37: 62-65.

Redmond, M.S., K H. Scott, R.C. Swartz and J.K.P. Jones. 1994. Preliminary culture and life-cycle experiments with the benthic amphipod *Ampelisca abdita*. Environ. Toxicol. Chem. 13(8): 1355-1365.

Rehwoldt, R., et al. 1972. The effect of increased temperature upon the acute toxicity of some heavy metal ions. Bull. Environ. Contam. Toxicol. 8: 91.

Rehwoldt, R., et al. 1973. The acute toxicity of some heavy metals ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10: 291.

Reichert, W.L., et al. 1979. Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 63C: 229.

Reid, S.D. and D.G. McDonald. 1991. Metal binding activity of the gills of rainbow trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 48: 1061-1068.

Reinfelder, J.R. and N.S. Fisher. 1994a. The assimilation of elements ingested by marine planktonic bivalve larvae. Limnol. Oceanogr. 39(1): 12-20.

Reinfelder, J.R. and N.S. Fisher. 1994b. Retention of elements absorbed by juvenile fish (*Menidia menidia*, *Menidia beryllina*) from zooplankton prey. Limnol. Oceanogr. 39(8): 1783-1789.

Reinfelder, J.R., W.X. Wang, S.N. Luoma and N.S. Fisher. 1997. Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels. Mar. Biol. 129: 443-452.

Reish, D.J. 1993. Effects of metals and organic compounds on survival and bioaccumulation in two species of marine gammaridean amphipod, together with a summary of toxicological research on this group. Journal of Natural History. 27: 781-794.

Reish, D.J. and J.A. LeMay. 1991. Toxicity and bioconcentration of metals and organic compounds by polychaeta. Ophelia Suppl. 5: 653-660.

Reish, D.J., et al. 1976. The effect of heavy metals on laboratory populations of two polychaetes with comparisons to the water quality conditions and standards in Southern California marine waters. Water Res. 10: 299.

Reish, D.J., et al. 1978. Interlaboratory calibration experiments using the Polychaetous annelid *Capitella capitata*. Mar. Environ. Res. 1: 109.

Reish, D.J., S.L. Asato and J.A. Lemay. 1988. The effect of cadmium and DDT on the survival and regeneration in the amphinomid polychaete *Eurythoe complanata*. *In*: Proc. 7th Symp. Mar. Biol., June 1, 1988, LaPaz BCS, Mexico: 107-111.

Remacle, J., et al. 1982. Cadmium fate in bacterial microcosms. Water Air Soil Pollut. 18: 455.

Reynoldson, T.B., P.. Rodriguez and M.M Madrid. 1996. A comparison of reproduction, growth and acute toxicity in two populations of *Tubifex tubifex* (Muller, 1774) from the North American great lakes and Northern Spain. Hydrobiol. 334: 199-206.

Rhodes, L., E. Casillas, B. McKnight, W. Gronlund, M. Myers, O.P. Olson and B. McCain. 1985. Interactive effects of cadmium, polychlorinated biphenyls, and fuel oil on experimentally exposed English sole (*Parophrys vetulus*). Can J. Fish. Aquat. Sci. 42: 1870-1880.

Ribo, J.M. 1997. Interlaboratory comparison studies of the luminescent bacteria toxicity bioassay. pp. 283-294.

Rice, D.L. 1984. A simple mass transport model for metal uptake by marine macroalgae growing at different rates. Exp. Mar. Biol. Ecol. 82: 175-182.

Richelle, E., Y. Degoudenne, L. Dejonghe and G. Van de Vyver. 1995. Experimental and field studies on the effect of selected heavy metals on three freshwater sponge species: *Ephydatia fluviatilis*, *Ephydatia muelleri* and *Spongilla lacustris*. Arch. Hydrobiol. 135(2): 209-231.

Ridlington, J.W., et al. 1981. Metallothionein and Cu-chelation: characterization of metal-binding proteins from the tissues of four marine animals. Comp. Biochem. Physiol. 70B: 93.

Rifici, L.M., D.S. Cherry. J.L. Farris and J. Cairns, Jr. 1996. Acute and subchronic toxicity of methylene blue to larval fathead minnows (*Pimephales promelas*): implications for aquatic toxicity testing. Environmental Toxicology and Chemistry. 15(8): 1304- 1308.

Riisgard, H.V., E. Bjornestad and F. Mohlenberg. 1987. Accumulation of cadmium in the mussel *Mytilus edulis*: kinetics and importance of uptake via food and sea water. Mar. Biol. 96: 349-353.

Ringwood, A.H. 1989. Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isognomon californicum*, during chronic exposure. Mar. Biol. 102: 499-504.

Ringwood, A.H. 1990. The relative sensitivities of different life stages of *Isognomon californicum* to cadmium toxicity. Arch. Environ. Contam. Toxicol. 19: 338-340.

Ringwood, A.H. 1992a. Comparative sensitivity of gametes and early developmental stages of a sea urchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures. Arch. Environ. Contam. Toxicol. 22: 288-295.

Ringwood, A.H. 1992b. Effects of chronic cadmium exposures on growth of larvae of an Hawaiian bivalve, *Isognomon californicum*. 1992. Mar. Ecol. Prog. Ser. 83: 63-70.

Ringwood, A.H. 1993. Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs. Mar. Environ. Res. 35: 35-39.

Ritterhoff, J., G.P. Zauke and R. Dallinger. 1996. Calibration of the estuarine amphipods, *Gammarus zaddachi* Sexton (1912), as biomonitors: toxicokinetics of cadmium and possible role of inducible metal-binding proteins in Cd detoxification. Aquat. Toxicol. 34: 351-369.

Roberts, K.S., et al. 1979. A high molecular-weight cadmium-binding fraction isolated from the liver cytosol of trout exposed to environmentally relevant concentrations of the metal. Trans. Biochem. Soc. London. 7: 650.

Roch, M. and J.A. McCarter. 1984. Metallothionein induction, growth, and survival of chinook salmon exposed to zinc, copper, and cadmium. Bull. Environ. Contam. Toxicol. 32: 478-485.

Roch, M. and E.J. Maly. 1979. Relationship of cadmium-induced hypocalcemia with mortality in rainbow trout (*Salmo gairdneri*) and the influence of temperature on toxicity. Jour. Fish. Res. Board Can. 36: 1297.

Roesijadi, G. And G.W. Fellingham. 1987. Influence of Cu, Cd, and Zn preexposure on Hg toxicity in the mussel *Mytilus edulis*. Can. J. Fish. Aquat. Sci. 44: 680-684.

Rombough, P.J. 1985. The influence of the zona radiata on the toxicities of inc, lead, mercury, copper and silver ions to embryos of steelhead trout *Salmo gairdneri*. Comp. Biochem. Physiol. 82C(1): 115-117.

Rombough, P.J. and E.T. Garside. 1982. Cadmium toxicity and accumulation in eggs and alevins of Atlantic salmon *Salmo salar*. Can. Jour. Zool. 60: 2006.

Rombough, P.J. and E.T. Garside. 1984. Disturbed ion balance in alevins of Atlantic salmon *Salmo salar* chronically exposed to sublethal concentrations of cadmium. Can. J. Zool. 62: 1443-1450.

Romeo, M. and M. Gnassia-Barelli. 1995. Metal distribution in different tissues and in subcellular fractions of the Mediterranean clam *Ruditapes decussatus* treated with cadmium, copper, or zinc. Comp. Biochem. Physiol. 111C: 457-463.

Rosas, C. And P. Ramirez. 1993. Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* expose to hard and soft water. Bull. Environ. Contam. Toxicol. 51: 568-574.

Roseman, E.F., E.L. Mills, M. Rutzke, W.H. Gutenmann and D.J. Lisk. 1994. Absorption of cadmium from water by north American zebra and quagga mussels (*Bivalvia*: *dreissenidae*). Chemosphere. 28(4): 737-743.

Rosenberg, R. and J.D. Costlow. 1976. Synergistic effects of cadmium and salinity combined with constant and cycling temperatures on the larval development of two estuarine crab species. Mar. Biol. 38: 291.

Rosko, J.J. and J.W. Rachlin. 1977. The effect of cadmium, copper, mercury, zinc and lead on cell division, growth, and chloropyll a content of the chlorophyte *Chlorella vulgaris*. Bull. Torrey Bot. Club 104: 226.

Rouleau, C, M. Block and H. Tjalve. 1998. Kinetics and body distribution of waterborne $^{65}Zn(II)$, $^{109}Cd(II)$, $^{203}Hg(II)$, and $CH_3{}^{203}Hg(II)$ in phantom midge larvae (*Chaoborus americanus*) and effects of complexing agents. Environ. Sci. Technol. 32: 1230-1236.

Roux, D.J., P.L. Kempster, E. Truter and L. van der Merwe. 1993. Effect of cadmium and copper on survival and reproduction of *Daphnia pulex*. Water SA. 19(4): 269-274.

Rubinstein, N.I., et al. 1983. Accumulation of PCBs, mercury and cadmium by *Nereis virens*, *Mercenaria mercenaria* and *Palaemontes pugio* from contaminated harbor sediments. Aquat. Toxicol. 3: 249.

Safadi, R.S. 1998. The use of freshwater planarians in acute toxicity test with heavy metals. Verh. Internat. Verein. Limnol. 26: 2391-2392

Sajwan, K.S. and W.H. Ornes. 1994. Phytoavailability and bioaccumulation of cadmium in duckweed plants (*Spirodela polyrhiza* L. Schleid). J. Environ. Sci. Health. A29(5): 1035-1044.

Sanchiz, C., A.M. Garcia-Carrascosa and A. Pastor. 1999. Bioaccumulation of Hg, Cd, Pb and Zn in four marine phanerogams and the alga *Caulerpa prolifera* (Forsskal) Lamouroux from the east coast of Spain. Bot. Mar. 42(2): 157-164.

Sandau, E., P. Sandau and O. Pulz. 1996. Heavy metal sorption by microalagae. Acta Biotechnol. 16(4): 227-235.

Sangalang, G.B. and H.C. Freeman. 1979. Tissue uptake of cadmium in brook trout during chronic sublethal exposure. Arch. Environ. Contam. Toxicol. 8: 77.

Sangalang, G.B. and M.J. O'Halloran. 1972. Cadmium-induced testicular injury and alterations of androgen synthesis in brook trout. Nature 240: 470.

Sangalang, G.B. and M.J. O'Halloran. 1973. Adverse effects of cadmium on brook trout testis and on in vitro testicular androgen synthesis. Biol. Reprod. 9:394.

Santiago-Fandino, V.J.R. 1983. The effects of nickel and cadmium on the growth rate of *Hydra littoralis* and an assessment of the rate of uptake of $^{63}Ni$ and $^{14}C$ by the same organism. Water Res. 17: 917.

Santojanni, A., G. Gorbi and F. Sartore. 1998. Prediction of fecundity in chronic toxicity tests on *Daphnia magna*. Water Res. 32(1): 3146-3156.

Sastry, K.V. and V. Shukla. 1994. Influence of protective agents in the toxicity of cadmium to a freshwater fish (*Channa punctatus*). Bull. Environ. Contam. Toxicol. 53: 711-717.

Sastry, K.V. and K. Sunita. 1982. Effect of cadmium and chromium on the intestinal absorption of glucose in the snakehead fish, *Channa punctatus*. Toxicol. Letters. 10: 293.

Sauter, S., et al. 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and fry of seven fish species. EPA-600/3-76-105. National Technical Information Service, Springfield, Virginia.

Sauvant, M.P., D. Pepin, C.A. Groliere and J. Bohatier. 1995. Effects of organic and inorganic substances on the cell proliferation of L-929 *Fibroblasts* and *Tetrahymena* toxicological bioassays. Bull. Environ. Contam. Toxicol. 55: 171-178.

Sauvant, M.P., D. Pepin, J. Bohatier, C.A. Groliere and J. Guillot. 1997. Toxicity assessment of 16 inorganic environmental pollutants by six bioassays. Ecotoxicol. Environ. Safety. 37: 131-140.

Saxena, K.K., A.K. Dubey and R.R.S. Chauhan. 1993. Experimental studies on toxicity of zinc and cadmium to *Heteropneustes fossilis* (Bl.) J. Freshwater Biol. 5(4): 343-346.

Schaeffer, D.J., M. Goehner, E. Grebe, L.G. Hansen, K. Hankenson, E.E. Herricks, G. Matheus, A. Miz, R. Reddy and K. Trommater. 1991. Evaluation of the “reference toxicant” addition procedure for testing the toxicity of environmental samples. Bull. Environ. Contam. Toxicol. 47: 540-546.

Schafer, H., A. Wenzel, U. Fritsche, G. Roderer and W. Traunspurger. 1993. Long-term effects of selected xenobiotica on freshwater green algae: development of a flow-through test system. The Science of the Total Environment, Supplement. pp. 735-740.

Schafer, H., H. Hettler, U. Fritsche, G. Pitzen, G. Roderer and A Wenzel. 1994. Biotests using unicellular algae and ciliates for predicting long-term effects of toxicants. Ecotoxicol. Environ. Safety. 27: 64-81.

Scherer, E., R.E. McNicol and R.E. Evans. 1997. Impairment of lake trout foraging by chronic exposure to cadmium: a black-box experiment. Aquatic Toxicology. 37: 1-7.

Schubauer-Berigan, M.K., J.R. Dierkes, P.D. Monson and G.T. Ankley. 1993. pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to *Ceriodaphnia dubia*, *Pimephales promelas*, *Hyalella azteca* and *Lumbriculus variegatus*. Environmental Toxicology and Chemistry. 12: 1261-1266.

Schuster, C.N. and B.H. Pringle. 1969. Trace metal accumulation by the American oyster, *Crassostrea virginica*. Proc. Natl. Shellfish Assoc. 59: 91.

Scott, K.J., et al. Manuscript. Toxicological methods using the benthic amphipod *Ampelisca abdita* Mills. U.S. EPA, Narragansett, Rhode Island.

Sedlacek, J., E.T. Gjessing and T Kallqvist. 1989. Influence of different aquatic humus fractions on uptake of cadmium to alga *Selenastrum capriconutum* Printz. Sci. Total Environ. 81/82: 711-718.

Sehgal, R. and A.B. Saxena. 1987. Determination of acute toxicity levels of cadmium and lead to the fish *Lebistes reticulatus* (Peters). Int. J. Environ. Stud. 29: 157-161.

Sekkat, N., A. Le Du, J.M. Jouany and M. Guerbet. 1992. Study of the interactions between copper, cadmium, and ferbam using the protozoan *Colpidium campylum* bioassay. Ecotoxicol. Environ. Safety. 24: 294-300.

Selby, D.A., J.M. Ihnat and J.J. Messer. 1985. Effects of subacute cadmium exposure on a hardwater mountain stream microcosm. Water Res. 19(5): 645-655.

Seyfreid, P.L. and C.B.L. Horgan. 1983. Effect of cadmium on lade water bacteria as determined by the luciferase assay of adenosine triphosphate. In: W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802, American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 425.

Shanmukhappa, H. and K. Neelakantan. 1990. Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular alga, *Synechosystis aquatilis*. Bull. Environ. Contam. Toxicol. 44: 840-843.

Sharma, M.S. and C.S. Selvaraj. 1994. Zinc, lead and cadmium toxicity to selected freshwater zooplankters. Poll. Res. 13(2): 191-201.

Sharp, J.R. and J.L. Kaszubski. 1989. The influence of exposure duration on the embryotoxicity of cadmium to the freshwater teleost, *Etheostoma spectabile*. Trace Subst. Environ. Health. 23: 277-289.

Shazili, N.A.M. and D. Pascoe. 1986. Variable sensitivity of rainbow trout (*Salmo gairdneri*) eggs and alevins to heavy metals. Bull. Environ. Contam. Toxicol. 36: 468-474.

Shcherban, E.P. 1977. Toxicity of some heavy metals for *Daphnia magna* Strauss, as a function of temperature. Hydrobiol. Jour. 13(4): 75.

Sheela, M., G. Mallika and S. Muniandy. 1995. Impact of cadmium on food utilization, growth and body composition in the fish *Oreochromis mossambicus*. Environ. Ecol. 13(2): 410-414.

Sherman, R.E., S.P. Gloss and L.W. Lion. 1987. A comparison of toxicity test conducted in the laboratory and in experimental ponds using cadmium and the fathead minnow (*Pimephales promelas*). Wat. Res. 21(3): 317-323.

Shivaraj, K.M. and H.S. Patil. 1988. Toxicity of cadmium and copper to a freshwater fish *Puntius arulius*. Environ. Ecol. 6(1): 5-8

Shukla, J.P. and K. Pandey. 1988. Toxicity and long term effects of a sublethal concentration of cadmium on the growth of the fingerlings of *Ophiocephalus punctatus* (Bl.). Acta Hydrochim. Hydrobiol. 16(5): 537-540.

Sick, L.V. and G. Baptist. 1979. Cadmium incorporation by the marine copepod *Pseudodiaptomous coronatus*. Limnol. Oceanogr. 24: 453.

Sidoumou, Z., M. Gnassia-Barelli and M. Romeo. 1997. Cadmium and calcium uptake in the mollusc *Donax rugosus* and effect of a calcium channel blocker. Bull. Environ. Contam. Toxicol. 58: 318-325.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena and M.A. Sampayo. 1988. Effect of nutrients, temperature and light on uptake of cadmium by *Selenastrum capricornutum* Printz. Water Res. 22(11): 1429-1435.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena, L.M.V.F. Machado, C.M.R. Pescada and M.L. de Moura. 1989. Effect of speciation on uptake and toxicity of cadmium to shrimp *Crangon crangon* (L.). Bull. Environ. Contam. Toxicol. 43: 287-294.

Sinha, S, M. Gupta and P. Chandra. 1994. Bioaccumulation and toxicity of Cu and Cd in *Vallisneria spiralis* (L.). Environ. Monit. Assess. 33(1): 75-84.

Skowronski, T. and M. Przytocka-Jusiak. 1986. Cadmium removal by green alga *Stichococcus bacillaris*. Chemosphere. 15(1): 77-79.

Skowronski, T., M. Jakubowski and B. Pawlik. 1985. Cadmium toxicity to green alga *Stichococcus bacillaris*. Acta Microbiologica Polonica. 34(3/4): 309.

Skowronski, T., B. Pawlik and M. Jakubowski. 1988. Reduction of cadmium toxicity to green microalga *Stichococcus bacillaris* by manganese. Bull. Environ. Contam. Toxicol. 41: 915-920.

Skowronski, T., S. Szubinska, B. Pawlik, M. Jakubowski, R. Bilewicz and E. Cukrowsak. 1991. The influence of pH on cadmium toxicity to the green alga *Stichococcus bacillaris* and on the cadmium forms present in the culture medium. Environ. Pollut. 74: 89-100.

Sloof, J.E., A. Viragh and B. Van der Veer. 1995. Kinetics of cadmium uptake by green algae. Water, Air Soil Pollut. 83: 105-122.

Slooff, W. 1983. Benthic macroinvertebrates and water quality assessment: some toxicological considerations. Aquat. Toxicol. 4: 73.

Slooff, W. and R. Baerselman. 1980. Comparison of the usefulness of the Mexican axoloth (*Ambystoma mexicanum*) and the clawed toad (*Xenopus laevis*) in toxicological bioassays. Bull. Environ. Contam. Toxicol. 24: 439.

Slooff, W.J., et al. 1983. Comparison of the susceptibility of 22 freshwater species to 15 chemical compounds. I. (sub)acute toxicity tests. Aquat. Toxicol. 4: 113.

Smith, D.P., J.H. Kennedy and K.L. Dickson. 1991. An evaluation of a naidid oligochaete as a toxicity test organism. Environmental Toxicology and Chemistry. 10: 1459-1465.

Smith, J.D., et al. 1981. Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem. Aust. Jour. Mar. Freshwater Res. 32: 151.

Smith, S. and M.K.H. Kwan. 1989. Use of aquatic macrophytes as a bioassay method to assess relative toxicity, uptake and accumulated forms of trace metals. Hydrobiologia. 188/189: 345-351.

Smokorowski, K.E., D.C. Lasenby and R.D. Evans. 1998. Quantifying the uptake and release of cadmium and copper by the opossum shrimp *Mysis relicta* preying upon the cladoceran *Daphnia magna* using stable isotope tracers. Can. J. Fish. Aquat. Sci. 55: 909-915.

Snell, T.W. and M.J. Carmona. 1995. Comparative toxicant sensitivity of sexual and asexual reproduction in the rotifer *Brachionus calyciflorus*. Environmental Toxicology and Chemistry. 14: 415-420.

Snell, T.W. and B.D. Moffat. 1992. A 2-d life cycle test with the rotifer *Brachionus calyciflorus*. Environmental Toxicology and Chemistry. 11: 1249-1257.

Snell, T.W. and G. Persoone. 1989a. Acute toxicity bioassays using rotifers. I. A test for brackish and marine environments with *Brachionus plicatilis*. Aquatic Toxicology. 14: 65-80.

Snell, T.W. and G. Persoone. 1989b. Acute toxicity bioassays using rotifers. II. A freshwater test with *Brachionus rubens*. Aquatic Toxicology. 14: 81-92.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991a. Acute toxicity test using rotifers. III. Effects of temperature, strain and exposure time on the sensitivity of *Brachionus plicatilis*. Environmental Toxicology and Water Quality: An International Journal. 6: 63-75.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991b. Acute toxicity tests using rotifers. Ecotoxicology and Environmental Safety. 21: 308-317.

Sobahn, R. and S.P.K. Sternberg. 1999. Cadmium removal using cladophora. J. Environ. Sci. Health. A34(1): 53-72.

Sorvari, J. and M. Sillanpaa. 1996. Influence of metal complex formation on heavy metal and free EDTA and DTPA acute toxicity determined by *Daphnia magna*. Chemosphere. 33(6): 1119-1127.

Sosnowski, S. and J. Gentile. 1978. Toxicological comparison of natural and cultured populations of *Acartia tonsa* to cadmium, copper and mercury. Jour. Fish. Res. Board Can. 35: 1366.

Sovenyi, J. and J. Szakolczai. 1993. Studies on the toxic and immunosuppressive effects of cadmium on the common carp. Acta Veterinaria Hungarica. 41(3-4): 415-426.

Spehar, R.L. 1976a. Cadmium and zinc toxicity to flagfish, *Jordanella floridae*. Jour. Fish. Res. Board Can. 33: 1939.

Spehar, R.L. 1976b. Cadmium and zinc toxicity to *Jordanella floridae*. EPA-600/3-76-096. National Technical Information Service, Springfield, Virginia.

Spehar, R.L. 1982. Memorandum to J.G. Eaton. U.S. EPA, Duluth, Minnesota. February 24.

Spehar, R.L. and A.R. Carlson. 1984a. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. PB84-153196. National Technical Information Service, Springfield, Virginia.

Spehar, R.L. and A.R. Carlson. 1984b. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. Environ. Toxicol. Chem. 3: 651.

Spehar, R.L. and J.T. Fiandt. 1986. Acute and chronic effects of water quality criteria-based metal mixtures on three aquatic species. Environmental Toxicology and Chemistry. 5: 917-931.

Spehar, R.L., et al. 1978. Toxicity and bioaccumulation of cadmium and lead in aquatic invertebrates. Environ. Pollut. 15: 195.

Sprague, J.B. 1985. Factors that modify toxicity. In: Fundamentals of aquatic toxicology. Rand, G.M. and S.R. Petrocelli (eds.). Hemisphere Publishing Company, New York, N.Y. pp.124-163.

Spry, D.J. and J.G. Wiener. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: a critical review. Environ. Pollut. 243-304.

Srivastava, A. and K.J. Appenroth. 1995. Interaction of EDTA and iron on the accumulation of $Cd^{2+}$ in duckweeds (Lemnaceae). J. Plant Physiol. 146: 173-176.

Stackhouse, R.A. and W.H. Benson. 1988. The influence of humic acid on the toxicity and bioavailability of selected trace metals. Aquatic Toxicology. 13: 99-108.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian water-milfoil (*Myriophyllum spicatum* L.). Arch. Environ. Contam. Toxicol. 2: 331.

Stary, J. and K. Kratzer. 1982. The cumulation of toxic metals on alga. Int. Jour. Environ. Anal. Chem. 12: 65.

Stary, J., et al. 1982. The cumulation of zinc and cadmium in fish (*Poecilia reticulata*). Int. Jour. Environ. Anal. Chem. 11: 117.

Stary, J., et al. 1983. Cumulation of zinc, cadmium and mercury on the alga *Scenedesmus obliquus*. Acta. Hydrochim. Hydrobiol. 11: 401.

Stebbing, A.R.D. 1976. The effects of low metal levels on a colonial hydroid. Jour. Mar. Biol. Assoc. U.K. 56: 1977.

Steele, R.L. and G.B. Thursby. 1983. A toxicity test using life stages of *Champia parvula* (Rhodophyta). In: W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 73.

Stephan, C.E., et al. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. National Technical Information Service, Springfield, Virginia.

Stephenson, M. and G.L. Macki. 1989. Net cadmium flux in *Hyalella azteca* (crustacea: amphipoda) populations from five central Ontario lakes. Sci. Total Environ. 87/88: 463-475.

Stephenson, M. and M.A. Turner. 1993. A field study of cadmium dynamics in periphyton and in *Hyalella azteca* (Crustacea: amphipoda). Water, Air, and Soil Pollution 68: 341-361.

Stern, M.S. and D.H. Stern. 1980. Effects of fly ash heavy metals on *Daphnia magna*. PB81-198327. National Technical Information Service, Springfield, Virginia.

Stom, D.I. and L.D. Zubareva. 1994. Comparative resistance of *Daphnia* and *Epischura* to toxic substances in acute exposure. Hydrobiol. J. 30(3): 35-38.

Stromberg, P.C., et al. 1983. Pathology of lethal and sublethal exposure of fathead minnows, *Pimephales promelas*, to cadmium: a model for aquatic toxicity assessment. Jour. Toxicol. Environ. Health 11: 247.

Stuhlbacher, A. and L. Maltby. 1992. Cadmium resistance in *Gammarus pulex* (l.). Arch. Environ. Contam. Toxicol. 22: 319-324.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1992. Induction of cadmium tolerance in two clones of *Daphnia magna* Straus. Comp. Biochem. Physiol. 101C(3): 571-577.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1993. Variation in the development of cadmium resistance in *Daphnia magna* Straus; effect of temperature, nutrition, age and genotype. Environ. Pollut. 80(2): 153-158.

Sullivan, B.K., et al. 1983. Effects of copper and cadmium on growth, swimming and predator avoidance in *Eurytemora affinis* (Copepoda). Mar. Biol. 77: 299.

Sunda, W.G. and S.A. Huntsman. 1996. Antagonisms between cadmium and zinc toxicity and manganese limitation in a coastal diatom. Limnol. Oceanogr. 41(3): 373-387.

Sunda, W.G., et al. 1978. Effect of chemical speciation on toxicity of cadmium to grass shrimp, *Palaemonetes pugio*: importance of free cadmium ion. Environ. Sci. Technol. 12: 409.

Sunderman, F.W., Jr., M.C. Plowman and S.M. Hopfer. 1991. Embryotoxicity and teratogenicity of cadmium chloride in *Xenopus laevis*, assayed by the FETAX procedure. Annals of Clinical and Laboratory Science. 21(6): 381-391.

Sunil, P.P.G, N. Siriwardena, K.J. Rana and D.J. Baird. 1995. A method for partitioning cadmium bioaccumulated in small aquatic organisms. Environ. Toxicol. Chem. 14(9): 1575-1577.

Sunila, I. and R. Lindstrom. 1985. Survival, growth and shell deformities of copper- and cadmium-exposed mussels (*Mytilus edulis* L.) In brackish water. Estuarine Coastal Shelf Sci. 21(4): 555-565.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993a. Effect of lethal and sublethal concentrations of cadmium on energetics in the gills of fry and fingerlings of *Cyprinus carpio*. Bull. Environ. Contam. Toxicol. 51: 920-926.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993b. Patterns of cadmium accumulation in the organs of fry and fingerlings of freshwater fish *Cyprinus carpio* following cadmium exposure. Chemosphere. 26(5): 945-953.

Suzuki, K.T., H. Sunaga, E. Kobayashi and S. Hatakeyama. 1987. Environmental and injected cadmium are sequestered by two major isoforms of basal copper, zinc-metallothionein in gibel (*Carassius auratus langsdorfi*) liver. Comp. Biochem. Physiol. 87C(1): 87-93.

Swinehart, J.H. 1990. Final Technical report for U.S.G.S. grant: the effects of humic substances on the interactions of metal ions with organisms and liposomes. Department of chemistry, University of California, Davis, CA 95616: 103.

Takamura, N., F. Kasai and M.M. Watanabe. 1989. Effects of Cu, Cd and Zn on photosynthesis of freshwater benthic algae. J. Appl. Phycol. 1: 39-52.

Talbot, V. 1985. Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*. Mar. Biol. 85: 51-54.

Talbot, V. 1987. Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: a water-quality criterion. Mar. Biol. 94: 557-560.

Taraldsen, J.E. and T.J. Norberg-King. 1990. New method for determining effluent toxicity using duckweed (*Lemna minor*). Environ. Toxicol. Chem. 9: 761-767.

Tarzwell, C.M. and C. Henderson. 1960. Toxicity of less common metals to fishes. Ind. Wastes 5: 12.

Taylor, G., D.J. Baird and A.M.V.M. Soares. 1998. Surface binding of contaminants by algae: consequences for lethal toxicity and feeding to *Daphnia magna* Straus. Environ. Toxicol. Chem. 17(3): 412-419.

Temara, A., G. Ledent, M. Warnau, H. Paucot, M. Jangoux and P. Dubois. 1996a. Experimental cadmium contamination of *Asterias rubens* (Echinodermata). Mar. Ecol. Prog. Ser. 140: 83-90.

Temara, A., M. Warnau, G. Ledent, M. Jangoux and P. Dubois. 1996b. Allometric variations in heavy metal bioconcentration in the asteroid *Asterias rubens* (Echinodermata). Bull. Environ. Contam. Toxicol. 56: 98-105.

Ten Hoopen, H.J.G., P.J. Nobel, A. Schaap, A. Fuchs and J.A. Roels. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. I. Development of cadmium tolerance in batch cultures. Antonie van Leeuwenhoek. 51: 344-346.

Tessier, A., Y. Couillard, P.G.C. Campbell and J.C. Auclair. 1993. Modeling Cd partitioning in oxic lake sediments and Cd concentrations in the freshwater bivalve *Anodonta grandis*. Limnol Oceanogr. 38(1): 1-17.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994a. Comparative study of the cadmium and mercury kinetics between the short-lived gastropod *Viviparus georgianus* (lea) and pelecypod *Elliptio complanata* (lightfoot), under laboratory conditions. Environ. Pollut. 271-282.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994b. Temperature effects on cadmium and mercury kinetics in freshwater molluscs under laboratory conditions. Arch. Environ. Contam. Toxicol. 26:179-184.

Tessier, L. G. Vaillancourt and L. Pazdernik. 1996. Laboratory study of Cd and Hg uptake by two freshwater molluscs in relation to concentration, age and exposure time. Water, Air Soil Pollut. 86: 347-357.

Thaker, A.A. and A.A. Haritos. 1989. Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*. Comp. Biochem. Physiol. 94C(1): 63-70.

Thebault, M.T., A. Biegniewska, J.P. Raffin and E.F. Skorkowski. 1996. Short term cadmium intoxication of the shrimp *Palaemon serratus*: effect on adenylate metabolism. Comp. Biochem. Physiol. 113C(3): 345-348.

Theede, H., et al. 1979. Temperature and salinity effects on the acute toxicity of cadmium to *Laomedea loveni* (Hydrozoa). Mar. Ecol. Progress Series 1:13.

Thellen, C., C. Blaise, Y. Roy and C. Hickey. 1989. Round robin testing with the *Selenastrum capricornutum* microplate toxicity assay. Hydrobiologia. 188/189: 259-268.

Thomann, R.V., F. Shkreli and S. Harrison. 1997. A pharmacokinetic model of cadmium in rainbow trout. Environ. Toxicol. Chem. 16(11): 2268-2274.

Thomas, D.G., A. Cryer, J.F. De L.G. Solbe and J. Kay. 1983. A comparison of the accumulation and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson). Comp. Biochem. Physiol. 76C(2): 241-246.

Thomas, D.G., M.W. Brown, D. Shurben, J.F. Del G. Solbe, A. Cryer and J. Kay. 1985. A comparison of the sequestration of cadmium and zinc in the tissues of rainbow trout (*Salmo gairdneri*) following exposure to the metals singly or in combination. Comp. Biochem. Physiol. 82C(1): 55-62.

Thompson, P.A. and P. Couture. 1991. Short- and long-term changes in growth and biochemical composition of *Selenastrum capricornutum* populations exposed to cadmium. Aquatic Toxicology. 21: 135-144.

Thompson, S.E., et al. 1972. Concentration factors of the chemical elements in edible aquatic organisms. UCRL-50564. Rev. 1. National Technical Information Service, Springfield, Virginia.

Thongra-ar, W. and O. Matsuda. 1995. Effects of cadmium and zinc on growth of *Thalassiosira weissflogii* and *Heterosigma akiashiwo*. *In*: A. Snidvongs, W. Utoomprukporn and M. Hungspreugs (eds.), 1995, Proceedings of the NRCT-JSPS Joint Seminar on Marine Science, December 2-3, 1993, Chulalongkorn University, Songkhla, Thailand. Bangkok: Department of Marine Science: 90-96.

Thorp, J.H. and S.P. Gloss. 1986. Field and laboratory tests on acute toxicity of cadmium to freshwater crayfish. Bull. Environ. Contam. Toxicol. 37: 355-361.

Thorp, J.H., et al. 1979. Effects of chronic cadmium exposure on crayfish survival, growth, and tolerance to elevated temperatures. Arch. Environ. Contam. Toxicol. 8: 449.

Thorpe, G.J. and J.D. Costlow. 1989. The relation of the acute (96-h) uptake and subcellular distribution of cadmium and zinc to cadmium toxicity in larvae of *Rhithropanopeus harrisii* and a *Palaemonetes pugio*. In: U.M. Cowgill and

L.R. Williams (eds.), Aquatic Toxicology and Hazard Assessment, ASTM STP 1027, Philadelphia, PA. 12: 82-94.

Thursby, G.B. and R.L. Steele. 1986. Comparison of short- and long-term sexual reproduction tests with the marine red alga *Champia Parvula*. Environmental Toxicology and Chemistry. 5: 1013-1018.

Timmermans, K.R., W. Peeters and M. Tonkes. 1992. Cadmium, zinc, lead and copper in *Chironomus riparius* (Meigen) larvae (Diptera, Chironomidae): uptake and effects. Hydrobiologia. 241: 119-134.

Tomasik, P., C.M. Magadza, S. Mhizha and A. Chirume. 1995a The metal-metal interactions in biological systems. Part III. *Daphnia magna*. Water, Air Soil Pollut. 82: 695-711.

Tomasik, P, C.M. Magadza, S. Mhizha, A. Chirume, M.F. Zaranyika and S. Muchiriri. 1995b Metal-metal interaction in biological systems. Part IV. Freshwater snail *Bulinus globosus*. Water, Air Soil Pollut. 83: 123-145.

Torres, E., A. Cid, C. Herrero and J. Abalde. 1998. Removal of cadmium ions by the marine diatom *Phaeodactylum tricornutum* Bohlin accumulation and long-term kinetics of uptake. Bioresource Technology. 63: 213-220.

Tortell, P.D. and N.M. Price. 1996. Cadmium toxicity and zinc limitation in centric diatoms of the genus *Thalassiosira*. Mar. Ecol. Prog. Ser. 138: 245-254.

Toudal, K. and H.U. Riisgard. 1987. Acute and sublethal effects of cadmium on ingestion, egg production and life-cycle development in the copepod *Acartia tonsa*. Mar. Ecol. Prog. Ser. 37: 141-146.

Toussaint, M.W., T.R. Shedd, W.H. Van der Schalie and G.R. Leather. 1995. A comparison of standard acute toxicity test with rapid-screening toxicity test. Environ. Toxicol. Chem. 14(5): 907-915.

Trehan, K. And Maneesha. 1994. Cadmium mediated control of nitrogenase activity and other enzymes in a nitrogen fixing cyanobacterium. Acta Microbiol. Hungarica. 41(4): 441-449.

Trevors, J.T., G.W. Stratton and G.M. Gadd. 1986. Cadmium transport, resistance, and toxicity in bacteria, algae, and fungi. Can. J. Microbiol. 32: 447-464.

Tucker, R.K. 1979. Effects of in vivo cadmium exposure on ATPases in gill of the lobster, *Homarus americanus*. Bull. Environ. Contam. Toxicol. 23: 33.

Tucker, R.K. and A. Matte. 1980. In vitro effects of cadmium and lead on ATPases in the gill of the rock crab, *Cancer irroratus*. Bull. Environ. Contam. Toxicol. 24: 847.

Twagilimana, L., J. Bohatier, C-A. Groliere, F. Bonnemoy and D. Sargos. 1998. A new low-cost microbiotest with the protozoan *Spirostomum teres*: culture conditions and assessment of sensitivity of the ciliate to 14 pure chemicals. Ecotoxicology and Environmental Safety. 41: 231-244.

Tyurin, A.N. and N.K. Khristoforova. 1993. Effect of toxicants on the development of the chiton *Ischnochiton hakodadensis*. Russ. Mar. Biol. 29(5/6): 100-106.

U.S. EPA. 1976. Quality criteria for water. EPA-440/9-76-023. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1980. Ambient water quality criteria for cadmium. EPA-440/5-80-025. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983a. Methods for chemical analysis of water and wastes. EPA-600/4-79-020 (Revised March 1983). National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983b. Water quality standards regulation. Federal Register 48: 51400. November 8.

U.S. EPA. 1983c. Water quality standards handbook. Office of Water Regulations and Standards, Washington, D.C.

U.S. EPA. 1985. Ambient water quality criteria for cadmium. EPA-440/5-84-032 (Revised late 1984). National Technical Information Service, Springfield , VA.

U.S. EPA. 1991. Technical support document for water quality-based toxics control. EPA-505/2-90-001. Office of Water, Washington, D.C.

U.S. EPA. 1994a. Water quality standards handbook, second ed. EPA-823-B-94-005b. Office of Water, Washington, D.C.

U.S. EPA. 1994b. Interim guidance on determination and use of water-effect ratios for metals. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA-823-B-94-001

U.S. EPA. 1999a. National Recommended Water Quality Criteria -- Correction. EPA-822-Z-99-001. Office of Water, Washington, D.C.

U.S. EPA. 1999b. Integrated approach to assessing the bioavailability and toxicity of metals in surface water and sediments. EPA-822-E-99-001. Office of Water, Washington, D.C.

Udoidiong, O.M., P.M. Akpan. 1991. Toxicity of cadmium, lead and lindane to Egeria radiata *Lamarck* (*Lamellibranchia, Donacidae*). Rev. Hydrobiol. Trap. 24(2): 111-117.

Uthe, J.F., et al. 1982. Cadmium in American lobster (*Homarus americanus*) from the area of a lead smelter. Can. Tech. Rept. Fish. Aquat. Sci. No. 1163.

Valencia, R., M. Gerpe, J. Trimmer, T. Buckman, A.Z. Mason and P.E. Olsson. 1998. The effect of estrogen on cadmium distribution in rainbow trout (*Oncorhynchus mykiss*). Mar. Environ. Res. 46(1-5): 167-171.

Van den Hurk, P., M. Faisal and M.H. Roberts Jr. 1998. Interaction of cadmium and benzo[a]pyrene in mummichog (*Fundulus heteroclitus*): effects on acute mortality. Mar. Environ. Res. 46(1-5): 525-528.

Van der Heever, J.A. and J.U. Grobbelaar. 1996. The use of Selenastrum capricornutum growth potential as a measure of toxicity of a few selected compounds. Water SA 22(2): 183-191.

Van Gemert, J.M, H.J.G. Ten Hoopen, J.A. Roels and A. Fuchs. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. II.

Light-limited growth in continuous culture. Antonie van Leeuwenhoek. 51: 347-351.

Van Ginneken, L., M.J. Chowdhury and R. Blust. 1999. Bioavailability of cadmium and zinc to the common carp, *Cyprinus carpio*, in complexing environments: A test for the validity of the free ion activity model. Environ. Toxicol. Chem. 18(10): 2295-2304.

Van Leeuwen, C.J., P.S. Griffioen, W.H.A. Vergouw and J.L. Maas-Diepeveen. 1985a. Differences in susceptibility of early life stages of rainbow trout (*Salmo gairdneri*) to environmental pollutants. Aquatic Toxicology. 7: 59-78.

Van Leeuwen, C.J., W.J. Luttmer and P.S. Griffioen. 1985b. The use of cohorts and populations in chronic toxicity studies with *Daphnia magna*: a cadmium example. Ecotoxicol. Environ. Safety. 9: 26-39.

Van Leeuwen, C.J., G. Niebeek and M. Rijkeboer. 1987. Effects of chemical stress on the population dynamics of *Daphnia magna*: a comparison of two test procedures. Ecotoxicol. Environ. Safety. 14:1-11.

Van Steveninck, R.F.M., M.E. Van Steveninck and D.R. Fernando. 1992. Heavy-metal (Zn, Cd) tolerance in selected clones of duck weed (*Lemna minor*). Plant Soil. 146: 271-280.

Vanegas, C., S. Espina, A.V. Botello and S. Villanueva. 1997. Acute toxicity and synergism of cadmium and zinc in white shrimp, *Penaeus setiferus*, juveniles. Bull. Environ. Contam. Toxicol. 58: 87-92.

Vashchenko, M.A. and P.M. Zhadan. 1993. Ecological assessment of marine environment using two sea urchin tests. disturbance of reproduction and sediment embryotoxicity. Sci. Total Environ. pp1235-1245.

Vasseur, P and P. Pandard. 1988. Influence of some experimental factors o metals toxicity to *Selenastrum capricornutum*. Toxic. Assess. 3: 331-343.

Veldhuizen-Tsoerkan, M.B., D.A. Holwerda and D.I. Zandee. 1991. Anoxic survival time and metabolic parameters as stress indices in sea mussels

exposed to cadmium or polychlorinated biphenyls. Arch. Environ. Contam. Toxicol. 20: 259-265.

Verbost, P.M., G. Flik, R.A.C. Lock and S.E.W. Bonga. 1987. Cadmium inhibition of $Ca^{2+}$ uptake in rainbow trout gills. Am. J. Physiol. 253 (Regulatory Integrative Comp. Physiol. 22): R216-R221.

Verma, S.R., et al. 1980. Short term toxicity tests with heavy metals for predicting safe concentrations. Toxicol. Letters 1: 113.

Vernberg, W.B., et al. 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, *Uca pugilator*. In: F.J. Vernberg and W.B. Vernberg (eds.), Pollution and Physiology of Marine Organisms. Academic Press, New York. p. 381.

Vernberg, W.B., et al. 1977. Effects of sublethal concentrations of cadmium on adult *Paleomonetes pugio* under static and flow-through conditions. Bull. Environ. Contam. Toxicol. 17: 16.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1981. Effects of some environmental factors on the toxicity of cadmium to the copepod *Tisbe holothuriae*. Arch. Hydrobiol. 91: 287.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1982. Differentiation of the sensitivity to copper and cadmium in different life stages of a copepod. Mar. Pollut. Bull. 13: 123.

Versteeg, D.J. 1990. Comparison of short- and long- term toxicity test results for the green alga, *Selenastrum capricornutum*. Plants for Toxicity Assessment. ASTM STP 1091. W. Wang, J.W. Gorsuch and W.R. Lower (eds), American Society for Testing and Materials, Philadelphia. pp. 40-48.

Visviki, I. and J.W. Rachlin. 1991. The toxic action and interactions of copper and cadmium to the marine alga *Dunaliella minuta*, in both acute and chronic exposure. Arch. Environ. Contam. Toxicol. 20: 271-275.

Visviki, I. and J.W. Rachlin. 1994. Acute and chronic exposure of *Dunaliella salina* and *Chlamydomonas bullosa* to Copper and cadmium: effects on growth. Arch. Environ. Contam. Toxicol. 26: 149-153.

Vogiatzis, A.K. and N.S. Loumbourdis. 1998. Cadmium accumulation in liver and kidneys and hepatic metallothionein and glutathione levels in *Rana ridibunda*, after exposure to $CdCl_2$. Arch. Environ. Contam. Toxicol. 34: 64-68.

Voyer, R.A. 1975. Effect of dissolved oxygen concentration on the acute toxicity of cadmium to the mummichog, *Fundulus heteroclitus*. Trans. Am. Fish. Soc. 104: 129.

Voyer, R.A. and D.G. McGovern. 1991. Influence of constant and fluctuating salinity on responses of *Mysidopsis bahia* exposed to cadmium in a life-cycle test. Aquatic Toxicology. 19: 215-230.

Voyer, R.A. and G. Modica. 1990. Influence of salinity and temperature on acute toxicity of cadmium to *Mysidopsis bahia* Molenock. Arch. Environ. Contam. Toxicol. 19: 124-131.

Voyer, R.A., et al. 1977. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to combinations of cadmium and salinity at selected temperatures. Mar. Biol. 44: 117.

Voyer, R.A., et al. 1979. Hatching success and larval mortality in an estuarine teleost, *Menidia menidia* (Linnaeus), exposed to cadmium in constant and fluctuating salinity regimes. Bull. Environ. Contam. Toxicol. 23: 475.

Voyer, R.A., et al. 1982. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to mixtures of cadmium and silver in combination with selected fixed salinities. Aquat. Toxicol. 2: 223.

Vranken, G, R. Vanderhaeghen and C. Heip. 1985. Toxicity of cadmium to free-living marine and brackish water nematodes (*Monhystera microphthalma*, *Monhystera disjuncta*, *Pellioditis marina*). Dis. Aquat. Org. 1: 49-58.

Vuori, K.M. 1993. Influence of water quality and feeding habits on the whole-body metal concentrations in lotic trichopteran larvae. Limnol. 23(4): 301-308.

Vuori, K.M. 1994. Rapid behavioural and morphological responses of hydropsychid larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure. Environ. Pollut. 84: 291-299.

Vykusova, B., Z. Svobodova. 1987. Comparison of the sensitivity of male and female guppies (*Poecilia reticulata* Peters) to toxic substances. Bull. Vurh Vodnany. (CZE)(ENG ABS). 23(3): 20-23.

Vymazal, J. 1984. Short-term uptake of heavy metals by periphyton algae. Hydrobiol. 119: 171-179.

Vymazal, J. 1990a. Toxicity and accumulation of lead with respect to algae and cyanobacteria: a review. Acta Hydrochim. Hydrobiol. 18(5): 513-535.

Vymazal, J. 1990b. Uptake of lead, chromium, cadmium and cobalt by *Cladophora glomerata*. Bull. Environ. Contam. Toxicol. 44: 468-472.

Vymazal, J. 1995. Influence of pH on heavy metals uptake by *Cladophora glomerata*. Pol. Arch. Hydrobiol. 42(3): 231-237.

Wall, S.B., J.J. Isley and T.W. La Point. 1996. Fish Bioturbation of cadmium-contaminated sediments: factors affecting Cd availability to *Daphnia magna*. Environ. Toxicol. Chem. 15(3): 294-298.

Wallace, W.G. and G.R. Lopez. 1997. Bioavailability of biologically sequestered cadmium and the implications of metal detoxification. Mar. Ecol. Prog. Ser. 147: 149-157.

Walsh, G.E., L.L. McLaughlin, M.J. Yoder, P.H. Moody, E.M. Lores, J. Forester and P.B. Wessinger-Duvall. 1988. *Minutocellus polymorphus*: a new marine diatom for use in algal toxicity tests. Environmental Toxicology and Chemistry. 7: 925-929.

Walsh, K., R.H. Dunstan, R.N. Murdoch. 1995. Differential Bioaccumulation of heavy metals and organopollutants in the soft tissue and shell of the marine gastropod, *Austrocochlea constricta*. Arch. Environ. Contam. Toxicol. 28: 35-39.

Walsh, R.S. and K.A. Hunter. 1992. Influence of phosphorus storage on the uptake of cadmium by the marine alga *Macrocystis pyrifera*. Limnol. Oceanogr. 37(7): 1361-1369.

Wang, J., M. Zhang, J. Xu and Y, Wang. 1995. Reciprocal effect of Cu, Cd, Zn on a kind of marine alga. Water Res. 29(1): 209-214.

Wang, W. 1986. Toxicity tests of aquatic pollutants by using common duckweed. Environmental Pollution (Series B). 11: 1-14.

Wang, W.X. and N.S. Fisher. 1996. Assimilation of trace elements and carbon by the mussel *Mytilus edulis*: effects of food composition. Limnol. Oceanogr. 41(2): 197-207.

Wang, W.X. and N.S. Fisher. 1998. Accumulation of trace elements in a marine copepod. Limnol. Oceanogr. 43(2): 273-283.

Wang, W.X., N.S. Fisher and S.N. Luoma. 1996. Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*. Mar. Ecol. Prog. Ser. 140: 91-113.

Wani, G.P. 1986. Toxicity of heavy metals to embryonic stages of *Cyprinus carpio* communis Pollut. Res. 5(2): 47-51.

Warnau, M., G. Ledent, A. Temara, V. Alva, M. Jangoux and P. Dubois. 1995a. Allometry of heavy metal bioconcentration in the echinoid *Paracentrotus lividus*. Arch. Environ. Contam. Toxicol. 29: 393-399.

Warnau, M., G. Ledent, A. Temara, M Jangoux and P. Dubois. 1995b. Experimental cadmium contamination of the echinoid *Paracentrotus lividus*: influence of exposure mode and distribution of the metal in the organism. 116: 117-124.

Warnau, M., J.L. Teyssie and S.W. Fowler. 1995c. Effect of feeding on cadmium bioaccumulation in the echinoid *Paracentrotus lividus* (Echinodermata). Mar. Ecol. Prog. Ser. 126: 305-309.

Warnau, M., S.W. Fowler and J.L. Teyssie. 1996a. Biokinetics of selected heavy metals and radionuclides in two marine macrophytes: the seagrass *Posidonia oceanica* and the alga *Caulerpa taxifolia*. Mar. Environ. Res. 41(4): 343-362.

Warnau, M., M. Iaccarino, A. De Biase, A. Temara, M Jangoux, P. Dubois and G. Pagano. 1996b. Spermiotoxicity and embryotoxicity of heavy metals in the echinoid *Paracentrotus lividus*. Environ. Toxicol Chem. 15(11): 1931-1936.

Warnau, M., J.L., Teyssie and S.W. Fowler, 1997. Cadmium bioconcentration in the echinoid *Paracentrotus lividus*: influence of the cadmium concentration in seawater. Mar. Environ. Res. 43(4): 303-314.

Warnick, S.L. and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. Jour. Water Pollut. Control Fed. 41: 280.

Warren, L.A., A. Tessier and L. Hare. 1998. Modelling cadmium accumulation by benthic invertebrates in situ: the relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations. Limnol. Oceanogr. 43(7): 1442-1454.

Watling, H.R. 1981. Effects of metals on the development of oyster embryos. South African Jour. Sci. 77: 134.

Watling, H.R. 1982. Comparative study on the effects of zinc, cadmium, and copper on the larval growth of three oyster species. Bull. Environ. Contam. Toxicol. 28: 195.

Watling, H.R. 1983a. Accumulation of seven metals by *Crassostrea gigas*, *Crassostrea margaritacea*, *Perna perna*, and *Choromytilus meridionalis*. Bull. Environ. Contam. Toxicol. 30: 317.

Watling, H.R. 1983b. Comparative study on the effects of metals on the settlement of *Crassostrea gigas*. Bull. Environ. Contam. Toxicol. 31: 344.

Watson, C.F. 1988. Sublethal effects of cadmium exposure on freshwater teleosts. Northeast Louisiana University. pp. 136.

Weber, W.J., Jr. and W. Stumm. 1963. Mechanism of hydrogen ion buffering in natural waters. Jour. Am. Water Works Assoc. 55: 1553.

Weimin, Y., G.E. Batley and M. Ahsanuullah. 1994. Metal bioavailability to the soldier crab *Mictyris longicarpus*. Sci. Total Environ. 141: 27-44.

Weis, J.S., et al. 1981. Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (*Fundulus heteroclitus*). Rapp. P. v. Reun. Cons. Int. Explor. Mer. 178: 64.

Westerman, A.G. and W.J. Birge. 1978. Accelerated rate of albinism in channel catfish exposed to metals. Prog. Fish-Cult. 40: 143.

Westernhagen, H.V. and V. Dethlefsen. 1975. Combined effects of cadmium and salinity on development and survival of flounder eggs. Jour. Mar. Biol. Assoc. U.K. 55: 945.

Westernhagen, H.V., et al. 1975. Combined effects of cadmium and salinity on development and survival of garpike eggs. Helgol. Wiss. Meeresunters. 27: 268.

Westernhagen, H.V., et al. 1978. Fate and effects of cadmium in an experimental marine ecosystem. Helgol. Wiss. Meeresunters. 31: 471.

Westernhagen, H.V., et al. 1979. Combined effects of cadmium, copper and lead on developing herring eggs and larvae. Helgol. Wiss. Meeresunters. 32: 257.

White, D.H. and M.T. Finley. 1978a. Effects of dietary cadmium in mallard ducks. In: D.D. Hemphill (ed.), Trace Substances in Environmental Health-XII. University of Missouri, Columbia, Missouri. p. 220.

White, D.H. and M.T. Finley. 1978b. Uptake and retention of dietary cadmium in mallard ducks. Environ. Res. 17: 53.

White, D.H., et al. 1978. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. Jour. Toxicol. Environ. Health 4: 551.

White, S.L. and P.S. Rainbow. 1982. Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*. Mar. Ecol. Progress Series 8: 95.

White, S.L. and P.S. Rainbow. 1986. Accumulation of cadmium by *Palaemon elegans* (crustacea: decapoda). Mar. Ecol. Prog. Ser. 32: 17-25.

Wicklum, D. and R.W. Davies. 1996. The effects of chronic cadmium stress on energy acquisition and allocation in a freshwater benthic invertebrate predator. Aquatic Toxicology. 35: 237-252.

Wicklum, D., D.E.C. Smith and R.W. Davies. 1997. Mortality, preference, avoidance, and activity of a predatory leech exposed to cadmium. Arch. Environ. Contam. Toxicol. 32: 178-183.

Wicklund, A. and P. Runn. 1988. Calcium effects on cadmium uptake, redistribution, and elimination in minnows, *Phoxinus phoxinus*, acclimated to different calcium concentrations. Aquat. Toxicol. 13: 109-122.

Wicklund, A., P. Runn and L. Norrgren. 1988. Cadmium and zinc interactions in fish: effects of zinc on the uptake, organ distribution, and elimination of $^{109}Cd$ in the zebrafish, *Brachydanio rerio*. Arch. Environ. Contam. Toxicol. 17: 345-354.

Wier, C.F. and W.M. Walter. 1976. Toxicity of cadmium in the freshwater snail, *Physa gyrina* Say. Jour. Environ. Qual. 5: 359.

Wikfors, G.H. and R. Ukeles. 1982. Growth and adaptation of estuarine unicellular algae in media with excess copper, cadmium or zinc, and effects of metal-contaminated algal food on *Crassostrea virginica* larvae. Mar. Ecol. Progress Series 7: 191.

Wilczok, A., U. Mazurek, D. Tyrawska, B. Sosak-Swiderska. 1994. Effect of cadmium on the cell division of *Chlorella vulgaris* Beij. 1890, strain A-8. Pol. Arch. Hydrobiol. 41(1): 123-131.

Wildgust, M.A. and M.B. Jones. 1998. Salinity change and the toxicity of the free cadmium ion [$Cd^{2+}_{(aq)}$] to *Neomysis integer* (Crustacea: Mysidacea). Aquatic Toxicology. 41: 187-192.

Williams, C.J., D. Aderhold and R.G.J. Edyvean. 1998. Comparison between biosorbents for the removal of metal ions from aqueous solutions.

Williams, D.R. and J.P. Giesy, Jr. 1978. Relative importance of food and water sources to cadmium uptake by *Gambusia affinis* (Poeciliidae). Environ. Res. 16: 326.

Williams, K.A., D.W.J. Green and D. Pascoe. 1985. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates 1. Cadmium. Arch. Hydrobiol. 102(4): 461-471.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1986. The acute toxicity of cadmium to different larval stages of *Chironomus riparius* (diptera: chironomidae) and its ecological significance for pollution regulation. Oecologia. 70(3): 362-366.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1987. Effect of cadmium on oviposition and egg viability in *Chironomus riparius* (diptera: chironomidae). Bull. Environ. Contam. Toxicol. 38: 86-90.

Williams, P.L and D.B. Dusenbery. 1990. Aquatic toxicity testing using the nematode, *Caenorhabditis elegans*. Environmental Toxicology and Chemistry. 9:1285-1290.

Windom, H.L., et al. 1982. Metal accumulation by the polychaete *Capitella capitata*: influences of metal content and nutritional quality of detritus. Can. Jour. Fish. Aquat. Sci. 39: 191.

Winner, R.W. 1984. The toxicity and biaccumulation of cadmium and copper as affected by humic acid. Aquat. Toxicol. 5: 267.

Winner, R.W. 1986. Interactive effects of water hardness and humic acid on the chronic toxicity of cadmium to *Daphnia pulex*. Aquatic Toxicology. 8: 281-293.

Winner. R.W. 1988. Evaluation of the relative sensitivities of 7-d *Daphnia magna* and *Ceriodaphnia dubia* toxicity tests for cadmium and sodium pentachlorophenate. Environmental Toxicology and Chemistry. 7: 153-159.

Winner, R.W. and J.D. Gauss. 1986. Relationship between chronic toxicity and bioaccumulation of copper, cadmium and zinc as affected by water hardness and humic acid. Aquat. Toxicol. 8: 149-161.

Winner, R.W. and T.C. Whitford. 1987. The interactive effects of a cadmium stress, a selenium deficiency and water temperature on the survival and reproduction of *Daphnia magna* Straus. Aquatic Toxicology. 10: 217-224.

Winter, S. 1996. Cadmium uptake kinetics by freshwater mollusc soft body under hard and soft water conditions. Chemosphere. 32(10): 1937-1948.

Witeska, M., B. Jezierska and J. Chaber. 1995. The influence of cadmium on common carp embryos and larvae. Aquaculture. 129: 129-132.

Witzel, B. 1998. Uptake, storage and loss of cadmium and lead in the woodlouse *Porcellio scaber* (crustacea, isopoda). Water, Air, Soil Pollut. 108: 51-68.

Wong, C.K. 1989. Effects of cadmium on the feeding behavior of the freshwater cladoceran *Moina macrocopa*. 1989. Chemosphere. 18(7/8): 1681-1687.

Wong, C.K. and P.K. Wong. 1990. Life table evaluation of the effects of cadmium exposure on the freshwater cladoceran, *Moina macrocopa*. Bull. Environ. Contam. Toxicol. 44: 135-141.

Wong, P.T.S. 1987. Toxicity of cadmium to freshwater microorganisms, phytoplankton, and invertebrates.

Wong, P.T.S., et al. 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11: 367.

Woodall, C, N. Maclean and F. Crossley. 1988. Responses of trout fry (*Salmo gairdneri*) and Xenopus laevis tadpoles to cadmium and zinc. Comp. Biochem. Physiol. 89C(1): 93-99.

Woodling, J.D. 1993. Survival and mortality of brown trout (*Salmo trutta*) exposed to in situ acute toxic concentrations of cadmium and zinc. University of Colorado at Boulder. pp. 130.

Woodward, D.F., A.M. Farag, H.L. Bergman, A.J. DeLonay, E.E. little, C.E. Smith and F.T. Barrow. 1995. Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: effects on age-0 brown trout and rainbow trout. Can. J. Fish. Aquat. Sci. 52: 1994-2004.

Woodworth, J. and D. Pascoe. 1982. Cadmium toxicity to rainbow trout, *Salmo gairdneri* Richardson: a study of eggs and alevins. Jour. Fish Biol. 21: 47.

Woodworth, J. and D. Pascoe. 1983. Cadmium uptake and distribution in sticklebacks related to the concentration and method of exposure. Ecotoxicol. Environ. Safe. 7: 525-530.

Wren, M.J. and D. McCarroll. 1990. A simple and sensitive bioassay for the detection of toxic materials using a unicellular green alga. Environmental Pollution. 64: 87-91.

Wright, D.A. 1977. The effect of salinity on cadmium uptake by the tissues of the shore crab, *Carcinus maenas*. Exp. Biol. 67: 137.

Wright, D.A. 1988. Dose-related toxicity of copper and cadmium in striped bass larvae from the Chespeake Bay: field considerations. Wat. Sci. Tech. 20(6/7): 39-48.

Wright, D.A. and J.W. Frain. 1981. Cadmium toxicity in *Marinogammarus obtusatus*: effect of external calcium. Environ. Res. 24: 338.

Wright, D.A. and P.M. Welbourn. 1994. Cadmium in the aquatic environment: a review of ecological, physiological, and toxicological effects on biota. Environ. Reviews 2: 187-214.

Wright, D.A., M.J. Meteyer and F.D. Martin. 1985. Effect of calcium on cadmium uptake and toxicity in larvae and juveniles of striped bass (*Morone saxatilis*). Bull. Environ. Contam. Toxicol. 34(2): 196-204.

Wu, R.S.S., P.K.S. Lam and B. Zhou. 1997. A settlement inhibition assay with cyprid larvae of the barnacle *Balanus amphitrite*. Chemosphere. 35(9): 1867-1874.

Wundram, M., D. Selmar and M. Bahadir. 1996. The *Chlamydomonas* test: a new phytotoxicity test based on the inhibition of algal photosynthesis enables the assessment of hazardous leachates from waste disposals in salt mines. Chemosphere. 32(8): 1623-1632.

Xiaorong, W. J. Mei, S. Hao and X. Ouyong. 1997. Effects of chelation on the bioconcentration of cadmium and copper by carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 59: 120-124.

Xue, H. and L. Sigg. 1998. Cadmium speciation and complexation by natural organic ligands in freshwater. Analytica Chemica Acta. 363: 249-259.

Yager, C.M. and H.W. Harry. 1964. The uptake of radioactive zinc, cadmium and copper by the freshwater snail, *Taphius glabratus*. Malacologia 1: 339.

Yamamoto, Y and M. Inoue. 1985. Lethal tolerance of acute cadmium toxicity in rainbow trout previously exposed to cadmium. Bull. Jpn. Soc. Sci. Fish. 51(10): 1733-1735.

Zanders, I.P. and W.E. Rojas. 1996. Salinity effects on cadmium accumulation in various tissues of the tropical fiddler crab *Uca rapax*. Environ. Pollut. 94(3): 293-299.

Zaroogian, G.E. 1979. Studies on the depuration of cadmium and copper by the American oyster *Crassostrea virginica*. Bull. Environ. Contam. Toxicol. 23: 117.

Zaroogian, G.E. 1980. *Crassostrea virginica* as an indicator of cadmium pollution. Mar. Biol. (Berl.). 58(4): 275-284.

Zaroogian, G.E. and S. Cheer. 1976. Cadmium accumulation by the American oyster, *Crassostrea virginica*. Nature. 261: 408.

Zaroogian, G.E. and G. Morrison. 1981. Effect of cadmium body burdens in adult *Crassostrea virginica* on fecundity and viability of larvae. Bull. Environ. Contam. Toxicol. 27: 344.

Zauke, G.P., R. Von Lemm, H.G. Meurs and W. Butte. 1995. Validation of estuarine gammarid collectives (amphipoda: crustacea) as biomonitors for cadmium in semi-controlled toxicokinetic flow-through experiments. Environ. Pollut. 90(2): 209-219.

Zhang, M., J. Wang and J. Bao. 1992. Study on the relationship between speciation of heavy metals and their ecotoxicity. Chin. J. Oceanol. Limnol. 10(3): 215-222.

Zia, S. and D.G. McDonald. 1994. Role of the gills and gill chloride cells in metal uptake in the freshwater-adapted rainbow trout, *Oncorhynchus mykiss*. Can. J. Fish. Aquat. Sci. 51: 2482-2492.

Zou, E. And S. Bu. 1994. Acute toxicity of copper, cadmium, and zinc to the water flea, *Moina irrasa* (cladocera). Bull. Environ. Contam. Toxicol. 52: 742-748.

Zuiderveen, J.A. and W.J. Birge. 1997. The relationship between chronic values in toxicity tests with *Ceriodaphnia dubia*. Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (sixth volume), ASTM STP 1317, F.J. Dwyer, T.R. Doane and M.L. Hinman (eds), American Society for Testing and Materials. pp. 551-556.