Click here for
DISCLAIMER

Document starts on next page

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Criteria and Standards Division
Washington, DC 20460

EPA 440/5-84-026
January 1985

Water

EPA

Ambient Water Quality Criteria for

Mercury - 1984

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

MERCURY

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

DISCLAIMER

This report has been reviewed by the Criteria and Standards Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

AVAILABILITY NOTICE

This document is available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

NTIS Accession Number- PB85-227452

FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon a consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. The criteria contained in this document replace any previously published EPA aquatic life criteria.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. The criteria presented in this publication are such scientific assessments. Such water quality criteria associated with specific stream uses when adopted as State water quality standards under section 303 become enforceable maximum acceptable levels of a pollutant in ambient waters. The water quality criteria adopted in the State water quality standards could have the same numerical limits as the criteria developed under section 304. However, in many situations States may want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of the State water quality standards that the criteria become regulatory.

Guidelines to assist the States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency, have been developed by EPA.

Edwin L. Johnson
Director
Office of Water Regulations and Standards

ACKNOWLEDGMENTS

J. Howard McCormick
(freshwater author)
Environmental Research Laboratory
Duluth, Minnesota

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

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

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

Judy L. Crane
University of Wisconsin-Superior
Superior, Wisconsin

Clerical Support: Terry L. Highland

CONTENTS

TABLES

Introduction*

Mercury has long been recognized as one of the most toxic of the heavy metals, but only recently was it identified as a serious pollutant in the aquatic environment (National Research Council, 1978; National Research Council Canada, 1979; Nriagu, 1979). Elemental mercury is a heavy liquid at room temperature and was considered relatively inert, because it was assumed that it would quickly settle to the bottom of a body of water and remain there in an innocuous state. However, elemental mercury is oxidized to mercury(II) under natural conditions (Wood, 1974). Furthermore, mercury(II), whether discharged directly or produced from elemental mercury, can be methylated by both aerobic and anaerobic bacteria (Akagi, 1979; Beijer and Jernelov, 1979; Callahan, et al. 1979; Jernelov, 1971, 1972; Jernelov, et al. 1975; National Research Council, 1978; Summers and Silver, 1978; Thayer and Brinckman, 1982; Wright and Hamilton, 1982). Mercury(II) can also be methylated in the slime coat, liver, and intestines of fish (Jernelov, 1968; Matsumura, et al. 1975; Rudd, et al. 1980b), but methylation apparently does not occur in other tissues (Huckabee, et al. 1978; Matida, et al. 1971; Pennacchioni, et al. 1976) or in plants (Czuba and Mortimer, 1980). (The term "methylmercury" is used herein to refer only to monomethylmercury, and not to dimethylmercury or any other monoorganomercury salt or diorganomercury compound. Inorganic mercury(II) will be referred to as "mercury(II)".)

The importance of methylation may be reduced by demethylation (Bisogni, 1979; Ramamoorthy, et al. 1982). Demethylation might provide a feedback

*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.

mechanism that controls the concentration of methylmercury in sediment and in water. Jernelov, et al. (1975) cited a case in which low levels of methylmercury in fish from a highly contaminated area coincided with strong methylmercury degrading activity in the sediment. Demethylation also occurs in fish (Burrows and Krenkel, 1973; de Freitas, et al. 1981; Gage, 1964; Olson, et al. 1978), probably as part of the depuration mechanism.

Numerous factors such as alkalinity, ascorbic acid, chloride, dissolved oxygen, hardness, organic complexing agents, pH, sediment, and temperature probably affect the acute and chronic toxicity and bioaccumulation of the various forms of mercury (Amend, et al. 1969; Baker, et al. 1983; Feich, et al. 1972; Hahne and Kroontje, 1973; Jernelov, 1980; Ramamoorthy and Blumhagen, 1984; Ribeyre and Boudou, 1982; Rogers and Beamish, 1981, 1983; Rudd, et al. 1980a; Rudd and Turner, 1983a,b; Sharma, et al. 1982; Stokes, et al. 1983; Tsai, et al. 1975; Wren and MacCrimmon, 1983; Wright and Hamilton, 1982).

A variety of studies have been conducted on the effect of selenium on the acute toxicity of mercury (e.g., Birge, et al. 1981; Bowers, et al. 1980; De Filippis, 1979; Heisinger, 1981; Heisinger, et al. 1979; Klaverkamp, et al., 1983a; Lawrence and Holoka, 1983; Sharma and Davis, 1980c) and on the accumulation of mercury from food and water (e.g., Beijer and Jernelov, 1978; Chang, et al. 1983; Heisinger, et al. 1979; Klaverkamp, et al. 1983b; Rudd, et al. 1980a; Sharma and Davis, 1980c; Speyer, 1980; Turner and Swick, 1983). Available data do not, however, show that quantitative relationships are consistent enough for a variety of aquatic species to enable relating water quality criteria to any of these variables.

Because of the variety of forms of inorganic and organic mercury and lack of definitive information about their relative toxicities, no available analytical measurement is known to be ideal for expressing aquatic life criteria for mercury. Previous aquatic life criteria for mercury (U.S. EPA, 1980) were specified in terms of total recoverable mercury, which would probably be measured as total mercury (U.S. EPA, 1983a), but both of these measurements are probably too rigorous in some situations. Acid-soluble mercury (operationally defined as the mercury that passes through a 0.45 μm membrane filter after the sample is acidified to pH = 1.5 to 2.0 with nitric acid) is probably the best measurement at the present for the following reasons:

1. This measurement is compatible with all available data concerning toxicity of mercury to, and bioaccumulation of mercury by, aquatic organisms. No test results were rejected just because it was likely that they would have been substantially different if they had been reported in terms of acid-soluble mercury. For example, results reported in terms of dissolved mercury would not have been used if the concentration of precipitated mercury was substantial.
2. On samples of ambient water, measurement of acid-soluble mercury should measure all forms of mercury that are toxic to aquatic life or can be readily converted to toxic forms under natural conditions. In addition, this measurement should not measure several forms, such as mercury that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions. Although this measurement (and many others) will measure soluble, complexed forms of mercury, such as the EDTA complex of mercury(II), that probably have low toxicities to aquatic life, concentrations of these forms probably are negligible in most ambient water.

3. Although water quality criteria apply to ambient water, the measurement used to express criteria is likely to be used to measure mercury in aqueous effluents. Measurement of acid-soluble mercury should be applicable to effluents because it will measure precipitates, such as carbonate and hydroxide precipitates of mercury(II), that might exist in an effluent and dissolve when the effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of acid-soluble mercury might be used to determine whether the receiving water can decrease the concentration of acid-soluble mercury because of sorption.
4. The acid-soluble measurement should be useful for most metals, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration at the time of collection, as does the dissolved measurement.
6. The only treatment required at the time of collection is preservation by acidification to pH = 1.5 to 2.0, similar to that required for the total measurement.
7. Durations of 10 minutes to 24 hours between acidification and filtration probably will not affect the result substantially.
8. The carbonate system has a much higher buffer capacity from pH = 1.5 to 2.0 than it does from pH = 4 to 9 (Weber and Stumm, 1963).
9. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.
10. After acidification and filtration of the sample to isolate the acid-soluble mercury, the analysis for total acid-soluble mercury can be performed using permanganate and persulfate oxidation and cold vapor atomic absorption (U.S. EPA, 1983a), as with the total measurement.

Acid-soluble inorganic mercury can be measured by not breaking down the organomercury compounds before using cold vapor atomic absorption. Methylmercury has been measured using gas chromatography (Cappon, 1984; Hildebrand, et al. 1980; Paasivirta, et al. 1981), thin layer chromatography (Kudo, et al. 1982), and liquid chromatography (Gast and Kraak, 1979; MacCrehan and Durst, 1978).

Thus, expressing aquatic life criteria for mercury in terms of the acid-soluble measurement has both toxicological and practical advantages. On the other hand, because no measurement is known to be ideal for expressing aquatic life criteria for mercury or for measuring mercury in ambient water or aqueous effluents, measurement of both total acid-soluble mercury and total mercury in ambient water or effluent or both might be useful. For example, there might be cause for concern if total mercury is much above an applicable limit, even though total acid-soluble mercury is below the limit.

Unless otherwise noted, all concentrations reported herein are expected to be essentially equivalent to acid-soluble mercury concentrations. All concentrations are expressed as mercury, not as the chemical tested. The criteria presented herein supersede previous aquatic life water quality criteria for mercury (U.S. EPA, 1976, 1980) because these new criteria were derived using improved procedures and additional information. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA, 1983b), which may include not only site-specific criterion concentrations (U.S. EPA, 1983c), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA, 1985). The latest literature search for information for this document was conducted in May, 1984; some newer information was also used.

Acute Toxicity to Aquatic Animals

Table 1 contains the primary acute toxicity data for three classes of mercury compounds: mercury(II), methylmercury, and other mercury compounds, chiefly organic. The latter information exists principally because many of these compounds were considered for use in treatment of diseases and control of parasites in fish culture, although their source for environmental concern is from industrial and agricultural uses for fungus control. Both phenylmercuric acetate and pyridylmercuric acetate have been called PMA. Tests have been conducted on different formulations which contain various percentages of active ingredient and the percentages of active ingredient given by the authors were used to calculate mercury concentrations. When the percentage of active ingredient was not given for pyridylmercuric acetate, 80 percent was assumed (Allison, 1957).

The freshwater acute toxicity values indicate that the difference in sensitivity between different species to a particular mercury compound is far greater than the difference in sensitivity of a particular species to various mercury compounds. For example, the reported acute values for mercury(II) range from 2.217 μg/L for Daphnia pulex to 2,000 μg/L for the aquatic stages of certain insects, with a continual gradation in sensitivity among intermediate species (Table 3). On the other hand, Joshi and Rege (1980), Lock and van Overbeeke (1981) and Matida, et al. (1971) found that various species were 4 to 31 times more sensitive to various organic mercury compounds than to mercuric chloride (Table 1).

MacLeod and Pessah (1973) studied the effect of temperature on the acute toxicity of mercuric chloride to rainbow trout. At 5, 10, and 15 C, the LC50s were 400, 280, and 220 μg/L, respectively (Tables 1 and 6). Clemens and Sneed (1958b) found a similar effect of temperature on toxicity to juvenile channel catfish; at 10, 16.5, and 24 C the acute values for phenylmercuric acetate were 1,960, 1,360, and 233 µg/L, respectively (Table 6).

The 28 Genus Mean Acute Values in Table 3 were calculated as geometric means of the available Species Mean Acute Values (Tables 1 and 3). Acute values are available for more than one species in each of two genera, and the range of Species Mean Acute Values within each genus is less than a factor of 1.6. On the other hand, a midge was among the most sensitive species, whereas other insects were the most resistant species. The most sensitive genus, Daphnia, is 756 times more sensitive than the most resistant, Acroneuria (Table 3). A freshwater Final Acute Value of 4.857 µg/L was obtained for mercury(II) using the Genus Mean Acute Values in Table 3 and the calculation procedure described in the Guidelines. Not enough data are available to calculate a Final Acute Value for methylmercury, but the available data indicate that it is more acutely toxic than mercury(II).

Saltwater fishes and invertebrates both show wide ranges of sensitivities to mercury(II). Acute values for fishes range from 36 µg/L for spot to 1,678 µg/L for winter flounder (Tables 1 and 3). Among invertebrates a mysid has an acute value of 3.5 µg/L, whereas the value for the soft-shell clam is 400 µg/L. Of the 29 saltwater genera for which acute values are available, the most sensitive, Mysidopsis, is 479 times more sensitive than the most resistant, Pseudopleuronectes. Acute values are available for more than one species in each of three genera and the range of Species Mean Acute Values within each genus is less than a factor of 1.7. The saltwater Final Acute Value of 4.125 µg/L was calculated for mercury(II) from the Genus Mean Acute Values in Table 3.

Chronic Toxicity to Aquatic Animals

Chronic toxicity tests with *Daphnia magna* have been conducted on three mercury compounds (Table 2). The renewal and flow-through techniques produced similar results for mercury(II), but the renewal technique produced much higher results for methylmercury, presumably because of volatility. In addition, a chronic test with brook trout on methylmercuric chloride yielded a chronic value of 0.5193 µg/L. Both an early life-stage test and a life-cycle test on mercuric chloride found adverse effects on the fathead minnow at all concentrations tested including the lowest of 0.23 µg/L. For mercuric chloride the acute-chronic ratio with *Daphnia magna* is less than 6, whereas that with the fathead minnow is greater than 600. For methylmercury the acute-chronic ratio with brook trout is 142.3.

A chronic value of 1.131 µg/L was obtained in a flow-through life-cycle exposure of a mysid to mercuric chloride (Table 2). Groups of 30 juvenile mysids were reared in each of 5 concentrations for 36 days at 21 C and a salinity of 30 g/kg. Effects examined included time to first spawn and productivity (total number of young/number of available female spawning days and total number of spawns/number of available female spawning days). No spawning occurred at 2.5 µg/L. Time to spawn and productivity at 1.6 µg/L were significantly different from the controls. The highest concentration at which no statistically significant effect on reproductive processes was detected was 0.8 µg/L. Therefore, the chronic limits are 0.8 and 1.6 µg/L and the chronic value is 1.131 µg/L. The 96-hr LC50 for this species in the same study was 3.5 µg/L, giving an acute-chronic ratio of 3.095 (Table 2).

The species mean acute-chronic ratio for *Daphnia magna* is 4.498, whereas that for the mysid is 3.095 (Table 3). These are sensitive species in fresh and salt water, respectively, and the four most sensitive species in each water are invertebrates. Thus, it seems reasonable to use the geometric mean of these two values as the Final Acute-Chronic Ratio (Table 3). Division of the Final Acute Values by 3.731 results in freshwater and saltwater Final Chronic Values of 1.302 and 1.106 µg/L, respectively. Even though the fathead minnow was considerably less sensitive than <u>Daphnia magna</u> in acute tests, the acute-chronic ratio for the fathead minnow is so high that its chronic value is below the Final Chronic Value and probably below the Final Residue Value (see below). If the acute-chronic ratio of greater than 649 for the fathead minnow is representative of ratios for other freshwater and saltwater fishes, then twelve of fourteen tested fish species, including the rainbow trout, coho salmon, bluegill, and haddock, would have chronic values below the Final Chronic Value. Various values for vertebrates in Table 6 are below the Final Chronic Value or are indicative of large acute-chronic ratios.

<u>Toxicity to Aquatic Plants</u>

Whereas some freshwater plant values for mercury(II) are about 1,000 µg/L (Table 4), effects of mercury(II) and methylmercury have been observed at concentrations below 10 µg/L, respectively (Table 6). Some organomercury compounds have affected algae at concentrations less than 1.0 µg/L (Table 6). Although freshwater plants are relatively insensitive to mercury(II) and sensitive to methylmercury, they do not appear to be more sensitive to methylmercury than freshwater animals.

Data concerning the toxicity of mercuric chloride to saltwater plants are from four studies with eight species of algae. The EC50s (Table 4) indicate reduction in growth at concentrations ranging from 10 to 160 µg/L. No data are available concerning the toxicities of organomercury compounds to saltwater plants.

Bioaccumulation

Bioconcentration is a function of the relative rates of uptake and depuration. The bioconcentration factor (BCF) of mercury is high for fish because uptake is relatively fast and depuration is very slow. Thus, the biological half-life of mercury in fish is approximately 2 to 3 years (de Freitas, et al. 1974, 1977; Jarvenpaa, et al. 1970; Lockhart, et al. 1972; McKim, et al. 1976; Mellinger, 1973; Ruohtula and Miettinen, 1975; Sharpe, et al. 1977). Depuration of mercury is so slow that, even in the absence of exposure to mercury, long-term reduction in the concentration of mercury in fish tissue is largely due to dilution by tissue addition from growth. Usually less than 60 percent of mercury in invertebrates is methylated, but in fish, except for young fish, usually more than 70 percent is methylated (Bache, et al. 1971; Baluja, et al. 1983; Busch, 1983; Cappon, 1984; Cappon and Smith, 1982a,b; Hattula, et al. 1978; Hildebrand, et al. 1980; Huckabee, et al. 1979; Kudo, et al. 1982; Luten, et al. 1980; Paasivirta, et al. 1983).

The distribution of mercury within a fish is the result of the movement of mercury from the absorbing surfaces (gills, skin, and gastrointestinal tract), into the blood, then to the internal organs, and eventually either to the kidney or bile for recycling or elimination or to muscle for long-term storage. As the tissue concentration approaches steady-state, net accumulation rate is slowed either by a reduction in uptake rate, possibly due to inhibition of membrane transport, or by an increase in depuration rate, possibly because of a saturation of storage sites, or both.

High concentrations of mercury in the slime coat of certain freshwater fishes, such as burbot, eels, and northern pike, and in the skin of acutely-exposed fishes are believed to be due to the methylating activity of bacteria prevalent in the mucous coat (Jernelov, 1968). In addition, acutely toxic concentrations of mercury have been reported to stimulate secretion of mucus (Baker, 1973; Lock, et al. 1981; McKone, et al. 1971). When acutely exposed fish are placed in mercury-free water, the skin quickly loses mercury, probably because of elimination of mercury(II) and sloughing of the slime coat (Burrows and Krenkel, 1973; Burrows, et al. 1974). The skin and mucous coat are in direct contact with mercury in water and can accumulate proportionately more mercury during short exposure than muscle. During long exposure there is sufficient time for mercury to reach more permanent storage sites.

Because sorption at the gill surface is a major pathway of mercury into aquatic organisms (Fromm, 1977), increases in temperature and activity cause increases in metabolic rate and ventilation rate and, therefore, uptake rate (de Freitas and Hart, 1975; Rogers and Beamish, 1981). The relationship between temperature and tissue residues seems to apply primarily before steady-state is reached (Reinert, et al. 1974) but also to some extent at steady-state (Boudou, et al. 1979; Cember, et al. 1978; Hartung, 1976). The latter is difficult to understand if steady-state results from saturation of available binding sites. Apparently not only are uptake and depuration accelerated by temperature (Ruohtula and Miettinen, 1975), but higher tissue residues also occur at higher temperatures, posibly because the uptake rate increases proportionately more than the depuration rate.

Similarly, low concentrations of dissolved oxygen are likely to increase both respiration rate and uptake rate. Larson (1976) found that the low concentration of dissolved oxygen in a eutrophic lake forced fishes into warmer surface waters to secure adequate oxygen. The warmer surface water apparently stimulated metabolic rate and increased mercury uptake.

Increased metabolic rate increases not only ventilation rate but also energy demand and thus increases food consumption and exposure to mercury through the food chain. Uptake through both the gills and the digestive tract is significant for fish, and some data suggest that tissue residues are higher in organisms exposed via both routes than via either separately (Boudou, et al. 1979; Phillips and Buhler, 1978). The relative importance of uptake from food for various fish species depends on such things as assimilation efficiency (Phillips and Gregory, 1979), body size, growth rate, and life span (Sharpe, et al. 1977), and diet (Murray, 1978). Although Murray (1978) did find different concentrations of mercury in different fish species, Huckabee (1972) and Huckabee, et al. (1974) found similar concentrations in both forage and game fish in the same environment.

Haines (1981) reported that acid rain tends to scour more mercury from the air. Acidification of a body of water might also increase mercury residues in fish even if no new input of mercury occurs, possibly because lower pH increases ventilation rate and membrane permeability, accelerates the rates of methylation and uptake, affects partitioning between sediment and water, or reduces growth or reproduction of fish (Akielaszek and Haines, 1981; Fromm, 1980; Hahne and Kroontje, 1973; Jernelov, 1980; Miller and Akagi, 1979; Ribeyre and Boudou, 1982; Rudd and Turner, 1983b; Scheider, et al. 1979; Stokes, et al. 1983; Tsai, et al. 1975; Wrenn and MacCrimmon, 1983). However, Heiskary and Helwig (1983) did not find a relation between pH and mercury in fish.

The available information (e.g., Boudou and Ribeyre, 1981; Boudou, et al. 1977, 1980; de Freitas, et al. 1981; Hamdy and Prabhu, 1979; Hamelink, et al. 1977; Herrick, et al. 1982; Huckabee, et al. 1979; Jernelov and Lann, 1971; Klaverkamp, et al. 1983c; MacCrimmon, et al. 1983; Norstrom, et al.

1976; Phillips, et al. 1980; Ribeyre, et al. 1980; Rogers and Beamish, 1982; Rogers and Qadri, 1982) indicates that the importance of uptake from food probably depends on the form and concentration of mercury in the diet and on the size and metabolic rate of the fish. Transfer of mercury from fish to wildlife predators has also been observed (Heinz, et al. 1980; Kucera, 1983; Wren, et al. 1983).

The available freshwater BCFs are listed in Tables 5 and 6. Table 5 contains BCFs only from those studies in which the exposure concentrations were adequately measured and the tissue residues reached steady-state or the test lasted longer than 27 days. Although the BCFs presented in Table 6 do not meet all these conditions, they do provide information on BCFs for plants and illustrate the very important influence of temperature on bioconcentration.

McKim, et al. (1976) studied the uptake of methylmercury into various tissues of brook trout. At concentrations in water of 0.93, 0.29, 0.09 and 0.03 µg/L the resulting concentrations in muscle after 273 days were 10,000, 5,000, 1,900, and 1,000 µg/kg and the corresponding BCFs were 11,000, 17,000, 21,000, and 33,000, respectively. Because the concentration of mercury in the muscle did not decrease as much as the concentration in water, the BCFs increased as the concentration in water decreased. A possible explanation for an inverse relationship between concentration in water and BCF is that steady-state results from saturation of available binding sites (Cember, et al. 1978). The maximum concentration in tissue would then be dependent on the number of available binding sites and would be independent of the concentration of mercury in water. If the concentration in tissue were constant, the BCF would be inversely proportional to the concentration in water. However, neither the concentration in tissue nor the BCF was constant. The comparable BCFs for the whole body were 10,000, 12,000, 12,000, and 23,000 and are lower than those for muscle. The fish were adversely affected at 0.93 μg/L, but for both muscle and whole body, the BCF at this concentration is in line with the other BCFs. Even though concentrations up to 0.29 μg/L did not cause statistically significant adverse effects, the concentration of mercury in fish exposed to 0.03 μg/L were at the FDA action level.

Olson, et al. (1975) obtained much higher BCFs for methylmercury with the fathead minnow, and the BCF was also concentration-dependent. As the concentration in the water decreased from 0.247 μg/L to 0.018 μg/L, the concentration in the fish decreased from 10,900 μg/kg to 1,470 μg/kg, but the BCF decreased from 44,100 to 81,700. The contrast between the results with the fathead minnow at 25 C (Olson, et al. 1975) and brook trout at 9 to 15 C (McKim, et al. 1976) is one of considerable interest and potential importance. The trout were fed pelleted feed, and so had little opportunity for food chain input. In contrast, the fathead minnow is a browser and probably fed not only on the introduced food but also on the Aufwuchs growing in the test solution to which mercury had been added. Thus the higher BCFs for the fathead minnow might be more representative of field situations in which fish are exposed to methylmercury via both the water and food (Phillips and Buhler, 1978; Phillips and Gregory, 1979; Rogers and Beamish, 1982). Also, because temperature affects bioconcentration, the fathead minnow might be more representative of commonly consumed warmwater fishes.

In a 75-day test, Niimi and Lowe-Jinde (1984) found 12 mg/kg in the whole body of rainbow trout exposed to 0.15 μg methylmercury/L (0.14 μg mercury/L) in water and 18 μg mercury/kg in food. The BCF of 85,700 is higher than the highest BCF obtained by Olson, et al. (1975). However, at 0.012 μg/L and 18 μg/kg, they found 0.053 mg/kg in the trout. This BCF of

4,077 is lower than the lowest BCF obtained by McKim, et al. (1976). Also, although both McKim, et al. (1976) and Olson, et al. (1975) found higher BCFs at lower concentrations in water, Niimi and Lowe-Jinde (1984) found just the opposite.

The FDA action level for mercury in fish and shellfish is 1.0 mg/kg (Table 5), and now only applies to the methylmercury in consumed tissues (U.S. FDA, 1984a,b). In their test on methylmercury, McKim, et al. (1976) found that brook trout exposed to 0.03 µg/L contained 1 mg/kg in muscle tissue. However, in their test on methylmercury with the fathead minnow, Olson, et al. (1975) found that exposure to 0.018 µg/L resulted in 1.47 mg/kg in the fish and a BCF of 81,700. Use of this BCF with the FDA action level results in a Final Residue Value of 0.012 µg/L for methylmercury (Table 5). The concentration in the fathead minnow is for whole body, but Heisinger, et al. (1979) found no significant difference between various body compartments. Further, Huckabee, et al. (1974) found that all fishes in a particular environment acquired about the same concentrations of mercury in both the whole body and muscle tissue when they were chronically exposed to low concentrations of mercury. On the other hand, Heiskary and Helwig (1983) and McKim, et al. (1976) found higher concentrations of mercury in the edible portion of fish than in the whole body. Thus the concentration of mercury in the muscle of some edible species is likely to exceed the FDA action level when exposed to methylmercury at a concentration of 0.012 µg/L.

Although the FDA action level only applies to methylmercury in fish and shellfish, it can be used to derive a water quality criterion for mercury(II) because most of the mercury in fish is methylmercury even if the organisms were exposed to inorganic mercury (de Freitas, et al. 1974; Jernelov and Lann, 1971). A BCF of 4,994 was obtained for mercuric chloride in a life-cycle test with the fathead minnow (Snarski and Olson, 1982). This BCF is based on the concentration of mercuric chloride in the water and the total concentration of organic and inorganic mercury in the tissue. Even though all concentrations tested caused adverse effects and the higher concentrations caused more severe effects, the BCFs were similar at all concentrations and were lower than those obtained with methylmercury by McKim, et al. (1976) and Olson, et al. (1975). Use of the BCF of 4,994 with the FDA action level of 1.0 mg/kg results in a freshwater Final Residue Value of 0.20 µg/L for mercury(II) (Table 5). This value of 0.20 µg/L derived for mercury(II) would, however, be too low if field BCFs are higher than laboratory BCFs, if waters contain substantial concentrations of methylmercury, or if methylation processes are accelerated in sediment.

Information on the bioconcentration of various mercury compounds by saltwater animals and plants is included in Tables 5 and 6 and by saltwater plankton in Table 6. For mercuric chloride, BCFs ranged from 853 to 10,920 with algae. In tests with the eastern oyster, BCFs of 10,000, 40,000, and 40,000 were obtained for mercuric chloride, methylmercuric chloride and phenylmercuric chloride, respectively (Kopfler, 1974). These are similar to the BCFs obtained with freshwater fish, but the BCF of 129 obtained for mercuric chloride in tail muscle of the American lobster is much lower.

To protect the marketability of saltwater shellfish for human consumption, Final Residue Values can be calculated based on the BCFs for the oyster and the FDA action level of 1.0 mg/kg. Accordingly, the Final Residue Values for mercuric chloride, methylmercuric chloride, and phenylmercuric chloride are 0.10, 0.025, and 0.025 µg/L, respectively. However, at these concentrations fifty percent of the exposed oysters would probably exceed the

FDA action level if all the mercury in the body were present as methylmercury.

Other Data

Most of the significant freshwater and saltwater results in Table 6 have already been discussed in connection with data in Tables 1-5, but a few additional items deserve special mention. Comparable tests with four species showed that mercuric cyanide was 0.67 to 50 times as toxic as mercuric chloride. Also, Birge, et al. (1979) reported that flow-through tests gave EC50s nearly two orders of magnitude lower than static tests with rainbow trout, catfish, goldfish, and largemouth bass (Table 6). Bouquegneau (1979) found that preexposure induced metallothionein production, which then protected the fish.

Molybdenum (Yamane and Koizumi, 1982) and vitamin E (Ganther, 1978, 1980) affects the toxicity of mercury to mammals, and probably many consumers of aquatic organisms, as does selenium (e.g., Alexander, et al. 1979; Berlin, 1978; National Research Council, 1978; National Research Council Canada, 1979; Stopford and Goldwater, 1975; Strom, et al. 1979). Wobeser, et al. (1976a,b) found methylmercury to be much less toxic to mink when they were fed freshwater drum, Aplodinolus grunniens, containing high mercury tissue residues than when they were fed a diet to which methylmercury chloride had been added. On the other hand, Albanus, et al. (1972) and Charbonneau, et al. (1974) found similar toxicity to cats when fed similar dietary concentrations of methylmercury, one as a tissue residue in pike and the other with methylmercury added to the ration.

Finley and Stendell (1978) and Heinz (1979a) fed black and mallard ducks, respectively, food contaminated with methylmercuric dicyandiamide.

These feeding studies extended over two and three generations, respectively, and demonstrated reduced hatching success and juvenile survival at mercury concentrations that were estimated to be equivalent to 0.5 and 0.1 mg/kg, respectively, in the natural succulent food of the wild ducks. These results were not used to estimate a Final Residue Value based on food for wildlife because the dicyandiamide compound might not represent the toxicity of methylmercury alone. Nevertheless, these tests suggest that the Final Residue Value might be an order of magnitude too high because at least one of these authors believes that the anion had little effect on the results (Heinz, 1979b).

Unused Data

Some data on the effects of mercury on aquatic organisms were not used because the studies were conducted with species that are not resident in North America (e.g., Ahsanullah, 1982; Akiyama, 1970; Dial, 1978a,b; Heisinger and Green, 1975; Jones, 1939a, 1940, 1973, 1975; Khangarot, et al. 1982; Kihlstrom and Hulth, 1972; Krishnaja and Rege, 1982; Mathur, et al. 1981; McClurg, 1984; Murti and Shukla, 1984; Nagashima, et al. 1983; Saxena and Parashari, 1983; Shaffi, 1981; Srivastava, 1982; van den Broek and Tracey, 1981; Verma, et al. 1984), or because the test species was not obtained in North America and was not identified well enough to determine if it is resident in North America (Hannerz, 1968). Brown and Ahsanullah (1971) conducted tests with brine shrimp, which species is too atypical to be used in deriving national criteria. Reviews by Chapman, et al. (1968), Eisler (1981), Eisler, et al. (1979), Phillips and Russo (1978), and Thompson, et al. (1972) only contain data that have been published elsewhere.

The 96-hr values reported by Buikema, et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema, et al. 1977). Applegate, et al. (1957) exposed only one or two organisms. Data were not used if the mode of exposure was inappropriate for deriving water quality criteria (Giblin and Massaro, 1973; Lucu and Skreblin, 1981; Schmidt-Nielson, et al. 1977; Weisbart, 1973). In addition, data were not used if mercury was a component of an effluent (Wong, et al. 1982) or if the test organisms were cultured in one water and tested in another (Bringmann and Kuhn, 1982). Bills, et al. (1977) and Passino and Cotant (1979) did not report any usable results. Jones (1935, 1938, 1939b, 1947), Miller (1980, 1981), and Nuzzi (1972) did not report a clearly defined endpoint.

Results of some laboratory tests were not used because the test was conducted in distilled water (McKone, et al. 1971), the quality of the dilution water or medium was questionable (Brkovic-Popovic and Popovic, 1977a,b; Carter and Cameron, 1973; Kim, et al. 1977a,b; Stary and Kratzer, 1982; Stary, et al. 1982, 1983), or because the test solution or culture medium contained too much EDTA which would probably complex mercury (Gutierrez-Galindo, 1981; Knowles and Zingmark, 1978; Stratton and Corke, 1979; Stratton, et al. 1979).

Data concerning concentrations of mercury in wild organisms (e.g., Abernathy and Cumbie, 1977; Armstrong and Scott, 1979; Bodaly, et al. 1984; Copeland and Ayers, 1972; DiNardi, et al. 1974; Flegal, et al. 1981; Helwig and Hora, 1983; Hildebrand, et al. 1980; Jensen, et al. 1981; Leonzio, et al. 1982; Martin, et al. 1984; May and McKinney, 1981; Mitchell, et al. 1982; Moore and Sutherland, 1980; Murray, 1978; Pennington, et al. 1982; Phillips and Buhler, 1980; Price and Knight, 1978; Ray, et al. 1984; Sheffy, 1978; Tsui and McCart, 1981; Wachs, 1982; Watling, et al. 1981) were not used to calculate bioaccumulation factors if the concentrations of mercury in the ambient water during the period of exposure was not adequately measured. Studies using isotopic mercury (e.g., Cunningham and Tripp, 1975; Glooschenko, 1969) were not used because of the possibility of isotopic discrimination.

Results of bioconcentration tests were not used if the tests were conducted in distilled water, were not long enough, were not flow-through, or if the concentration of mercury in the test solution was not adequately measured (e.g., Cunningham and Tripp, 1973; Kim, et al. 1977a,b; McKone, et al. 1971; Medeiros, et al. 1980; Middaugh and Rose, 1974; Phillips and Gregory, 1980; Ribeyre, et al. 1980; Sharma and Davis, 1980a; Stary and Kratzer, 1980, 1982; Stary, et al. 1980, 1981, 1982, 1983; Vernberg and O'Hara, 1972).

Summary

Data are available on the acute toxicity of mercury(II) to 28 genera of freshwater animals. Acute values for invertebrate species range from 2.2 µg/L for *Daphnia pulex* to 2,000 µg/L for three insects. Acute values for fishes range from 30 µg/L for the guppy to 1,000 µg/L for the Mozambique tilapia. Few data are available for various organomercury compounds and mercurous nitrate, and they all appear to be 4 to 31 times more acutely toxic than mercury(II).

Available chronic data indicate that methylmercury is the most chronically toxic of the tested mercury compounds. Tests on methylmercury with *Daphnia magna* and brook trout produced chronic values less than 0.07 µg/L. For mercury(II) the chronic value obtained with *Daphnia magna* was about 1.1 µg/L and the acute-chronic ratio was 4.5. In both a life-cycle test and an early life-stage test on mercuric chloride with the fathead minnow, the chronic value was less than 0.26 µg/L and the acute-chronic ratio was over 600.

Freshwater plants show a wide range of sensitivities to mercury, but the most sensitive plants appear to be less sensitive than the most sensitive freshwater animals to both mercury(II) and methylmercury. A bioconcentration factor of 4,994 is available for mercury(II), but the bioconcentration factors for methylmercury range from 4,000 to 85,000.

Data on the acute toxicity of mercuric chloride are available for 29 genera of saltwater animals including annelids, molluscs, crustaceans, echinoderms, and fishes. Acute values range from 3.5 µg/L for a mysid to 1,678 µg/L for winter flounder. Fishes tend to be more resistant and molluscs and crustaceans tend to be more sensitive to the acute toxic effects of mercury(II). Results of a life-cycle test with the mysid show that mercury(II) at a concentration of 1.6 µg/L significantly affected time of first spawn and productivity; the resulting acute-chronic ratio was 3.1.

Concentrations of mercury that affected growth and photosynthetic activity of one saltwater diatom and six species of brown algae range from 10 to 160 µg/L. Bioconcentration factors of 10,000 and 40,000 have been obtained for mercuric chloride and methylmercury with an oyster.

National Criteria

Derivation of a water quality criterion for mercury is more complex than for most metals because of methylation of mercury in sediment, in fish, and in the food chain of fish. Apparently almost all mercury currently being discharged is mercury(II). Thus mercury(II) should be the only important possible cause of acute toxicity and the Criterion Maximum Concentrations can be based on the acute values for mercury(II).

The best available data concerning long-term exposure of fish to mercury(II) indicates that concentrations above 0.23 µg/L caused statistically significant effects on the fathead minnow and caused the concentration of total mercury in the whole body to exceed 1.0 mg/kg. Although it is not known what percent of the mercury in the fish was methylmercury, it is also not known whether uptake from food would increase the concentration in the fish in natural situations. Species such as rainbow trout, coho salmon, and especially the bluegill, might suffer chronic effects and accumulate high residues of mercury about the same as the fathead minnow.

With regard to long-term exposure to methylmercury, McKim, et al. (1976) found that brook trout can exceed the FDA action level without suffering statistically significant adverse effects on survival, growth, or reproduction. Thus for methylmercury the Final Residue Value would be substantially lower than the Final Chronic Value.

Basing a freshwater criterion on the Final Residue Value of 0.012 µg/L derived from the bioconcentration factor of 81,700 for methylmercury with the fathead minnow (Olson, et al. 1975) essentially assumes that all discharged mercury is methylmercury. On the other hand, there is the possibility that in field situations uptake from food might add to the uptake from water. Similar considerations apply to the derivation of the saltwater criterion of 0.025 µg/L using the BCF of 40,000 obtained for methylmercury with the Eastern oyster (Kopfler, 1974). Because the Final Residue Values for methylmercury are substantially below the Final Chronic Values for mercury(II), it is probably not too important that many fishes, including the rainbow trout, coho salmon, bluegill, and haddock might not be adequately protected by the freshwater and saltwater Final Chronic Values for mercury(II).

In contrast to all the complexities of deriving numerical criteria for mercury, monitoring for unacceptable environmental effects should be relatively straightforward. The most sensitive adverse effect will probably be exceedence of the FDA action level. Therefore, existing discharges should be acceptable if the concentration of methylmercury in the edible portion of exposed consumed species does not exceed the FDA action level.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of mercury does not exceed 0.012 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 2.4 µg/L more than once every three years on the average. If the four-day average concentration exceeds 0.012 µg/L more than once in a three-year period, the edible portion of consumed species should be analyzed to determine whether the concentration of methylmercury exceeds the FDA action level.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of mercury does not exceed 0.025 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 2.1 µg/L more than once every three years on the average. If the four-day average concentration exceeds 0.025 μg/L more than once in a three-year period, the edible portion of consumed species should be analyzed to determine whether the concentration of methylmercury exceeds the FDA action level.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as "acid-soluble". Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

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 mercury 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).

Table 1. Acute Toxicity of Mercury to Aquatic Animals

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
			FRESHWATER SPECIES		
			Mercury(II)		
Tubificid worm, *Branchiura sowerbyi*	R, U	Mercuric chloride	80	80	Chapman, et al. 1982a
Tubificid worm, *Limnodrilus hoffmeisteri*	R, U	Mercuric chloride	180	180	Chapman, et al. 1982a,b
Tubificid worm, *Quistadrilus multisetosus*	R, U	Mercuric chloride	250	250	Chapman, et al. 1982a
Tubificid worm, *Rhyacodrilus montana*	R, U	Mercuric chloride	240	240	Chapman, et al. 1982a
Tubificid worm, *Spirosperma ferox*	R, U	Mercuric chloride	330	330	Chapman, et al. 1982a
Tubificid worm, *Spirosperma nikolskyi*	R, U	Mercuric chloride	500	500	Chapman, et al. 1982a
Tubificid worm, *Stylodrilus heringianus*	R, U	Mercuric chloride	140	140	Chapman, et al. 1982a
Tubificid worm, *Tubifex tubifex*	R, U	Mercuric chloride	140	140	Chapman, et al. 1982a,b
Tubificid worm, *Varichaeta pacifica*	R, U	Mercuric chloride	100	100	Chapman, et al. 1982a
Worm, *Nais* sp.	S, M	Mercuric nitrate	1,000	1,000	Rehwoldt, et al. 1973
Snail (embryo), *Amnicola* sp.	S, M	Mercuric nitrate	2,100***	-	Rehwoldt, et al. 1973
Snail (adult), *Amnicola* sp.	S, M	Mercuric nitrate	80	80	Rehwoldt, et al. 1973
Snail, *Aplexa hypnorum*	S, U	Mercuric chloride	370	370	Holcombe, et al. 1983

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Cladoceran, *Daphnia magna*	S, U	Mercuric chloride	<4.4****	-	Anderson, 1948
Cladoceran, *Daphnia magna*	S, U	Mercuric chloride	5	-	Biesinger & Christensen, 1972
Cladoceran, *Daphnia magna*	S, U	Mercuric chloride	3.177	-	Canton & Adema, 1978
Cladoceran, *Daphnia magna*	S, U	Mercuric chloride	1.478	-	Canton & Adema, 1978
Cladoceran, *Daphnia magna*	S, U	Mercuric chloride	2.180	-	Canton & Adema, 1978
Cladoceran (<6 hr old), *Daphnia magna*	S, U	Mercuric chloride	4.4	-	Barera & Adams, 1983
Cladoceran (<24 hr old), *Daphnia magna*	S, U	Mercuric chloride	4.4	-	Barera & Adams, 1983
Cladoceran (1-9 day old), *Daphnia magna*	S, U	Mercuric chloride	5.2-14.8***	3.157	Barera & Adams, 1983
Cladoceran, *Daphnia pulex*	S, U	Mercuric chloride	2.217	2.217	Canton & Adema, 1978
Amphipod, *Gammarus* sp.	S, M	Mercuric nitrate	10	10	Rehwoldt, et al. 1973
Crayfish (male, mixed ages), *Faxonella clypeatus*	R, M	Mercuric chloride	20	20	Heit & Fingerman, 1977; Heit, 1981
Crayfish, *Orconectes limosus*	S, M	Mercuric chloride	50	50	Boutet & Chaisemartin, 1973
Mayfly, *Ephemerella subvaria*	S, U	Mercuric chloride	2,000	2,000	Warnick & Bell, 1969
Damselfly, (Unidentified)	S, M	Mercuric nitrate	1,200	1,200	Rehwoldt, et al. 1973

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Stonefly, *Acroneuria lycorias*	S, U	Mercuric chloride	2,000	2,000	Warnick & Bell, 1969
Caddisfly, *Hydropsyche betteni*	S, U	Mercuric chloride	2,000	2,000	Warnick & Bell, 1969
Caddisfly, (Unidentified)	S, M	Mercuric nitrate	1,200	1,200	Rehwoldt, et al. 1973
Midge, *Chironomus* sp.	S, M	Mercuric nitrate	20	20	Rehwoldt, et al. 1973
Coho salmon (juvenile), *Oncorhynchus kisutch*	R, M	Mercuric chloride	240	240	Lorz, et al. 1978
Rainbow trout (juvenile), *Salmo gairdneri*	R, U	Mercuric chloride	155.1	-	Matida, et al., 1971
Rainbow trout (juvenile), *Salmo gairdneri*	FT, U	Mercuric chloride	280	-	MacLeod & Pessah, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	FT, U	Mercuric chloride	220	-	MacLeod & Pessah, 1973
Rainbow trout, *Salmo gairdneri*	FT, U	Mercuric chloride	420	-	Daoust, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	FT, M	Mercuric chloride	275	275	Lock & van Overbeeke, 1981
Fathead minnow, *Pimephales promelas*	FT, M	Mercuric chloride	168	-	Snarski & Olson, 1982
Fathead minnow, *Pimephales promelas*	FT, M	Mercuric chloride	150	158.7	Call, et al. 1983
Mosquitofish (female), *Gambusia affinis*	S, U	Mercuric chloride	180	180	Joshi & Rege, 1980
Guppy (116-157 mg), *Poecilia reticulata*	R, U	Mercuric chloride	30	-	Deshmukh & Marathe, 1980

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Guppy (362-621 mg), *Poecilia reticulata*	R, U	Mercuric chloride	53.5***	30	Deshmukh & Marathe, 1980
Bluegill (juvenile), *Lepomis macrochirus*	S, U	Mercuric chloride	160	160	Holcombe, et al. 1983
Mozambique tilapia, *Tilapia mossambica*	S, U	Mercuric chloride	1,000	1,000	Qureshi & Saksena, 1980
		Methylmercury			
Rainbow trout (juvenile), *Salmo gairdneri*	R, U	Methylmercuric chloride	25	-	Matida, et al. 1971
Rainbow trout (larva), *Salmo gairdneri*	R, U	Methylmercuric chloride	24	-	Wobeser, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	R, U	Methylmercuric chloride	42	-	Wobeser, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	FT, M	Methylmercuric chloride	24	24	Lock & van Overbeeke, 1981; Lock, et al. 1981
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	Methylmercuric chloride	84	-	McKim, et al. 1976
Brook trout (yearling), *Salvelinus fontinalis*	FT, M	Methylmercuric chloride	65	73.89	McKim, et al. 1976
		Other Mercury Compounds			
Rainbow trout (juvenile), *Salmo gairdneri*	R, U	Phenylmercuric acetate	5	5	Matida, et al. 1971
Rainbow trout (2 mos), *Salmo gairdneri*	FT, M	Mercurous nitrate	33.0	33.0	Hale, 1977
Goldfish, *Carassius auratus*	S, U	Phenylmercuric lactate	82	82	Ellis, 1947

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value** (µg/L)	Reference
Common carp, *Cyprinus carpio*	R, U	2-Methoxy ethyl mercuric chloride	139	139	Das & Misra, 1982
Fathead minnow, *Pimephales promelas*	S, M	Mercuric acetate	40	40	Curtis, et al. 1979; Curtis & Ward, 1981
Fathead minnow, *Pimephales promelas*	S, M	Mercuric thiocyanate	115	115	Curtis, et al. 1979; Curtis & Ward, 1981
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Ethylmercuric p-toluene sulfonanilide	51	51	Clemens & Sneed, 1959
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Ethylmercuric phosphate	49	49	Clemens & Sneed, 1959
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Phenylmercuric acetate	1,966	1,966	Clemens & Sneed, 1959
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Phenylmercuric acetate	28	28	Clemens & Sneed, 1958a, 1959
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Pyridylmercuric acetate	<176	-	Clemens & Sneed, 1958b
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Pyridylmercuric acetate	224	-	Clemens & Sneed, 1958b
Channel catfish (juvenile), *Ictalurus punctatus*	S, U	Pyridylmercuric acetate	<153	<182	Clemens & Sneed, 1958b
Mosquitofish (female), *Gambusia affinis*	S, U	Methoxy ethyl mercuric chloride	910	910	Joshi & Rege, 1980
Mosquitofish (female), *Gambusia affinis*	S, U	Phenylmercuric acetate	37	37	Joshi & Rege, 1980
Mosquitofish (female), *Gambusia affinis*	S, U	Phenylmercuric acetate (Ceresan)	44	44	Joshi & Rege, 1980

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value** (µg/L)	Reference
		SALTWATER SPECIES			
		Mercury(II)			
Polychaete worm (adult), *Neanthes arenaceodentata*	S, U	Mercuric chloride	96		Reish, et al. 1976
Polychaete worm (juvenile), *Neanthes arenaceodentata*	S, U	Mercuric chloride	100	97.98	Reish, et al. 1976
Sand worm (adult), *Nereis virens*	S, U	Mercuric chloride	70	70	Eisler & Hennekey, 1977
Polychaete worm (larva), *Capitella capitata*	S, U	Mercuric chloride	14	14	Reish, et al. 1976
Oligochaete worm, *Limnodriloides verrucosus*	R, U	Mercuric chloride	120	120	Chapman, et al. 1982a
Oligochaete worm, *Monopylephorus cuticulatus*	R, U	Mercuric chloride	230	230	Chapman, et al. 1982a
Oligochaete worm, *Tubificoides gabriellae*	R, U	Mercuric chloride	98	98	Chapman, et al. 1982a
Northern horse mussel, *Modiolus modiolus*	S, M	Mercuric chloride	230	230	Hilmy, et al. 1981
Blue mussel, *Mytilus edulis*	S, U	Mercuric chloride	5.8	5.8	Martin, et al. 1981
Bay scallop (juvenile), *Argopecten irradians*	S, U	Mercuric chloride	89	89	Nelson, et al. 1976
Pacific oyster, *Crassostrea gigas*	S, U	Mercuric chloride	6.7	-	Martin, et al. 1981
Pacific oyster, *Crassostrea gigas*	S, M	Mercuric chloride	5.7	-	Glickstein, 1978
Pacific oyster, *Crassostrea gigas*	S, M	Mercuric nitrate	5.5	5.944	Glickstein, 1978

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Eastern oyster, *Crassostrea virginica*	S, U	Mercuric chloride	5.6	-	Calabrese & Nelson, 1974; Calabrese, et al. 1977
Eastern oyster, *Crassostrea virginica*	S, U	Mercuric chloride	10.2	7.558	MacInnes & Calabrese, 1978
Common rangia (adult), *Rangia cuneata*	S, U	Mercuric chloride	10,000	-	Olson & Harrel, 1973
Common rangia (adult), *Rangia cuneata*	S, U	Mercuric chloride	8,700	-	Olson & Harrel, 1973
Common rangia (adult), *Rangia cuneata*	S, M	Mercuric chloride	58	-	Dillon, 1977
Common rangia (adult), *Rangia cuneata*	S, M	Mercuric chloride	122	*****	Dillon, 1977
Quahog clam, *Mercenaria mercenaria*	S, U	Mercuric chloride	4.8	4.8	Calabrese & Nelson, 1974; Calabrese, et al. 1977
Soft-shell clam (adult), *Mya arenaria*	S, U	Mercuric chloride	400	400	Eisler & Hennekey, 1977
Copepod, *Pseudodiaptomus coronatus*	S, U	Mercuric chloride	79	79	Gentile, 1982
Copepod, *Eurytemora affinis*	S, U	Mercuric chloride	158	158	Gentile, 1982
Copepod, *Acartia clausi*	S, U	Mercuric chloride	10	10	Gentile, 1982
Copepod (adult), *Acartia tonsa*	S, U	Mercuric chloride	10	-	Sosnowski & Gentile, 1978
Copepod (adult), *Acartia tonsa*	S, U	Mercuric chloride	14	-	Sosnowski & Gentile, 1978
Copepod (adult), *Acartia tonsa*	S, U	Mercuric chloride	15	-	Sosnowski & Gentile, 1978

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Copepod (adult), *Acartia tonsa*	S, U	Mercuric chloride	20	14.32	Gentile, 1982
Copepod, *Nitocra spinipes*	S, U	Mercuric chloride	230	230	Bengtsson, 1978
Mysid, *Mysidopsis bahia*	FT, M	Mercuric chloride	3.5	3.5	Gentile, et al. 1982, 1983; Lussier, et al. Manuscript
White shrimp (adult), *Penaeus setiferus*	S, U	Mercuric chloride	17	17	Green, et al. 1976
American lobster (larva), *Homarus americanus*	S, U	Mercuric chloride	20	20	Johnson & Gentile, 1979
Hermit crab (adult), *Pagurus longicarpus*	S, U	Mercuric chloride	50	50	Eisler & Hennekey, 1977
Dungeness crab (larva), *Cancer magister*	S, U	Mercuric chloride	8.2	-	Martin, et al. 1981
Dungeness crab (larva), *Cancer magister*	S, M	Mercuric chloride	6.6	7.357	Glickstein, 1978
Green crab (larva), *Carcinus maenas*	S, U	Mercuric chloride	14	14	Connor, 1972
Starfish (adult), *Asterias forbesi*	S, U	Mercuric chloride	60	60	Eisler & Hennekey, 1977
Haddock (larva), *Melanogrammus aeglefinus*	S, U	Mercuric chloride	98	98	Cardin, 1982
Mummichog, *Fundulus heteroclitus*	S, U	Mercuric chloride	300	-	Dorfman, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Mercuric chloride	200	-	Dorfman, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Mercuric chloride	300	-	Dorfman, 1977

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Mummichog, *Fundulus heteroclitus*	S, U	Mercuric chloride	300	-	Dorfman, 1977
Mummichog (adult), *Fundulus heteroclitus*	S, U	Mercuric chloride	800	-	Eisler & Hennekey, 1977
Mummichog (adult), *Fundulus heteroclitus*	S, U	Mercuric chloride	2,000	*****	Klaunig, et al. 1975
Mummichog (embryo), *Fundulus heteroclitus*	S, M	Mercuric chloride	67.4	67.4	Sharp & Neff, 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Mercuric chloride	144	-	Cardin, 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Mercuric chloride	125	-	Cardin, 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Mercuric chloride	86	115.7	Cardin, 1982
Tidewater silverside (juvenile), *Menidia peninsulae*	S, U	Mercuric chloride	71	71	Hansen, 1983
Fourspine stickleback (adult), *Apeltes quadracus*	S, U	Mercuric chloride	315	315	Cardin, 1982
Spot (juvenile), *Leiostomus xanthurus*	S, U	Mercuric chloride	36	36	Hansen, 1983
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Mercuric chloride	1,820	-	Cardin, 1982
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Mercuric chloride	1,560	-	Cardin, 1982

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Mercuric chloride	1,810	-	Cardin, 1982
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Mercuric chloride	1,320	-	Cardin, 1982
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Mercuric chloride	1,960	1,678	Cardin, 1982
		Methylmercury			
Amphipod (adult), *Gammarus duebeni*	S, U	Methylmercuric chloride	150	150	Lockwood & Inman, 1975
Mummichog (embryo), *Fundulus heteroclitus*	S, M	Methylmercuric chloride	51.1	51.1	Sharp & Neff, 1982
		Other Mercury Compounds			
Grass shrimp (adult), *Palaemonetes pugio*	S, M	Mercuric acetate	47	47	Curtis, et al. 1979; Curtis & Ward, 1981
Grass shrimp (adult), *Palaemonetes pugio*	S, M	Mercuric thiocyanate	76	76	Curtis, et al. 1979; Curtis & Ward, 1981
Mummichog, *Fundulus heteroclitus*	S, U	Mercurous sulfate	6,800	-	Dorfman, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Mercurous sulfate	300	*****	Dorfman, 1977

* S = static, R = renewal, FT = flow-through, U = unmeasured, M = measured.

** Results are expressed as mercury, not as the chemical.

*** Not used in calculation of Species Mean Acute Value because data are available for a more sensitive life stage.

**** "Less than" values were not used in calculations.

*****No Species Mean Acute Value calculated because acute values are too divergent for this species.

Table 2. Chronic Toxicity of Mercury to Aquatic Animals

Species	Test*	Chemical	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
		FRESHWATER SPECIES			
		Mercury(II)			
Cladoceran, *Daphnia magna*	LC***	Mercuric chloride	0.72-1.28	0.96	Biesinger, et al. 1982
Cladoceran, *Daphnia magna*	LC****	Mercuric chloride	0.91-1.82	1.287	Biesinger, et al. 1982
Fathead minnow, *Pimephales promelas*	LC	Mercuric chloride	<0.26*****	<0.26	Snarski & Olson, 1982
Fathead minnow, *Pimephales promelas*	ELS	Mercuric chloride	<0.23*****	<0.23	Call, et al. 1983
		Methylmercury			
Cladoceran, *Daphnia magna*	LC***	Methylmercuric chloride	<0.04*****	<0.04	Biesinger, et al. 1982
Cladoceran, *Daphnia magna*	LC****	Methylmercuric chloride	0.52-0.87	0.6726	Biesinger, et al. 1982
Brook trout, *Salvelinus fontinalis*	LC	Methylmercuric chloride	0.29-0.93	0.5193	McKim, et al. 1976.
		Other Mercury Compounds			
Cladoceran, *Daphnia magna*	LC****	Phenylmercuric acetate	1.12-1.90	1.459	Biesinger, et al. 1982
		SALTWATER SPECIES			
		Mercury(II)			
Mysid, *Mysidopsis bahia*	LC	Mercuric chloride	0.8-1.6	1.131	Gentile, et al. 1982, 1983; Lussier, et al. Manuscript

Table 2. (Continued)

* LC = life cycle or partial life cycle, ELS = early life stage.

** Results are expressed as mercury, not as the chemical.

*** Flow-through

**** Renewal

*****Adverse effects occurred at this concentration, which was the lowest concentration tested.

Acute-Chronic Ratio

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
	Mercury(II)		
Cladoceran, *Daphnia magna*	5	0.96	5.208
Cladoceran, *Daphnia magna*	5	1.287	3.885
Fathead minnow, *Pimephales promelas*	168	<0.26	>646.2
Fathead minnow, *Pimephales promelas*	150	<0.23	>652.2
Mysid, *Mysidopsis bahia*	3.5	1.131	3.095
	Methylmercury		
Brook trout *Salvelinus fontinalis*	73.89[†]	0.5193	142.3

[†] Geometric mean of 2 values from McKim, et al. (1976) in Table 1.

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

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
		Mercury(II)		
28	2,000	Stonefly, *Acroneuria lycorias*	2,000	-
27	2,000	Mayfly, *Ephemerella subvaria*	2,000	-
26	2,000	Caddisfly, *Hydropsyche betteni*	2,000	-
25	1,200	Caddisfly, (Unidentified)	1,200	-
24	1,200	Damselfly, (Unidentified)	1,200	-
23	1,000	Worm, *Nais* sp.	1,000	-
22	1,000	Mozambique tilapia, *Tilapia mossambica*	1,000	-
21	406.2	Tubificid worm, *Spirosperma ferox*	330	-
		Tubificid worm, *Spirosperma nikolskyi*	500	-
20	370	Snail, *Aplexa hypnorum*	370	-
19	275	Rainbow trout, *Salmo gairdneri*	275	-
18	250	Tubificid worm, *Quistadrilus multisetosus*	250	-
17	240	Tubificid worm, *Rhyacodrilus montana*	240	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
16	240	Coho salmon, *Oncorhynchus kisutch*	240	-
15	180	Tubificid worm, *Limnodrilus hoffmeisteri*	180	-
14	180	Mosquitofish, *Gambusia affinis*	180	-
13	160	Bluegill, *Lepomis macrochirus*	160	-
12	158.7	Fathead minnow, *Pimephales promelas*	158.7	>649.2**
11	140	Tubificid worm, *Tubifex tubifex*	140	-
10	140	Tubificid worm, *Stylodrilus heringianus*	140	-
9	100	Tubificid worm, *Varichaeta pacifica*	100	-
8	80	Tubificid worm, *Branchiura sowerbyi*	80	-
7	80	Snail, *Amnicola* sp.	80	-
6	50	Crayfish, *Orconectes limosus*	50	-
5	30	Guppy, *Poecilia reticulata*	30	-
4	20	Crayfish, *Faxonella clypeatus*	20	-
3	20	Midge, *Chironomus* sp.	20	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
2	10	Amphipod, *Gammarus* sp.	10	-
1	2,646	Cladoceran, *Daphnia magna*	3,157	4.498**
		Cladoceran, *Daphnia pulex*	2,217	-
		SALTWATER SPECIES		
		Mercury(II)		
29	1,678	Winter flounder, *Pseudopleuronectes americanus*	1,678	-
28	400	Soft-shell clam, *Mya arenaria*	400	-
27	315	Fourspine stickleback, *Apeltes quadracus*	315	-
26	230	Northern horse mussel, *Modiolus modiolus*	230	-
25	230	Copepod, *Nitocra spinipes*	230	-
24	230	Oligochaete worm, *Monophylephorus cuticulatus*	230	-
23	158	Copepod, *Eurytemora affinis*	158	-
22	120	Oligochaete worm, *Limnodriloides verrucosus*	120	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
8	14	Green crab, *Carcinus maenas*	14	-
7	14	Polychaete worm, *Capitella capitata*	14	-
6	11.97	Copepod, *Acartia clausi*	10	-
		Copepod, *Acartia tonsa*	14.32	
5	7.357	Dungeness crab, *Cancer magister*	7.357	-
4	6.703	Pacific oyster, *Crassostrea gigas*	5.944	-
		Eastern oyster, *Crassostrea virginica*	7.558	-
3	5.8	Blue mussel, *Mytilus edulis*	5.8	-
2	4.8	Quahog clam, *Mercenaria mercenaria*	4.8	-
1	3.5	Mysid, *Mysidopsis bahia*	3.5	3.095

* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

**Geometric mean of two values in Table 2.

Table 3. (Continued)

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
21	98	Oligochaete worm, *Tubificoides gabriellae*	98	-
20	98	Haddock, *Melanogrammus aeglefinus*	98	-
19	97.98	Polychaete worm, *Neanthes arenaceodentata*	97.98	-
18	90.63	Atlantic silverside, *Menidia menidia*	115.7	-
		Tidewater silverside, *Menidia peninsulae*	71	-
17	89	Bay scallop, *Argopecten irradians*	89	-
16	79	Copepod, *Pseudodiaptomus coronatus*	79	-
15	70	Sand worm, *Nereis virens*	70	-
14	67.4	Mummichog, *Fundulus heteroclitus*	67.4	-
13	60	Starfish, *Arterias forbesi*	60	-
12	50	Hermit crab, *Pagurus longicarpus*	50	-
11	36	Spot, *Leiostomus xanthurus*	36	-
10	20	American lobster, *Homarus americanus*	20	-
9	17	White shrimp, *Penaeus setiferus*	17	-

Table 3. (Continued)

Mercury(II)

Final Acute-Chronic Ratio = 3.731 (see text)

Fresh water

Final Acute Value = 4.857 µg/L

Criterion maximum concentration = (4.857 µg/L) / 2 = 2.428 µg/L

Final Chronic Value = (4.857 µg/L) / 3.731 = 1.302 µg/L

Salt water

Final Acute Value = 4.125 µg/L

Criterion maximum concentration = (4.125 µg/L) / 2 = 2.062 µg/L

Final Chronic Value = (4.125 µg/L) / 3.731 = 1.106 µg/L

Table 4. Toxicity of Mercury to Aquatic Plants

Species	Chemical	Effect	Result (µg/L)[a]	Reference
FRESHWATER SPECIES				
Mercury(II)				
Alga, *Chlorella vulgaris*	Mercuric chloride	33-day EC50 (cell division inhibition)	1,030	Rosko & Rachlin, 1977
Alga, *Chlorella vulgaris*	Mercuric chloride	LC50	100-1,000	Gipps & Biro, 1978
Alga, *Chlorella vulgaris*	Mercuric chloride	LC50	148-296	Rai, 1979; Rai, et al. 1981
Alga, *Chlorella vulgaris*	Mercuric chloride	15-day EC50 (growth)	443-592	Rai, et al. 1981
Alga, *Anabaena flos-aquae*	Mercuric chloride	EC50 (growth)	53	Thomas & Montes, 1978
Blue alga, *Microcystis aeruginosa*	Mercuric chloride	8-day incipient inhibition	5	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, *Scenedesmus quadricauda*	Mercuric chloride	8-day incipient inhibition	70	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b, 1979, 1980b
Alga, *Selenastrum capricornutum*	Mercuric chloride	Inhibited growth	59	Slooff, et al. 1983
Eurasian watermilfoil, *Myriophyllum spicatum*	Mercuric chloride	32-day EC50 (root weight)	3,400	Stanley, 1974
Methylmercury				
Alga, *Anabaena flos-aquae*	Methylmercuric chloride	EC50 (growth)	6.0	Thomas & Montes, 1978
Alga, *Chlorella vulgaris*	Methylmercuric chloride	15-day EC50 (growth)	0.8-4.0	Rai, et al. 1981

Table 4. (Continued)

Species	Chemical	Effect	Result (µg/L)*	Reference
		Other Mercury Compounds		
Alga, *Anabaena flos-aquae*	Phenylmercuric acetate	EC50 (growth)	2.8	Thomas & Montes, 1978
		SALTWATER SPECIES		
		Mercury(II)		
Alga, *Thalassiosira aestevalis*	Mercuric chloride	Reduced chlorophyll a	10	Hollibaugh, et al. 1980
Seaweed, *Ascophyllum nodosum*	Mercuric chloride	10-day EC50 (growth)	100	Stromgren, 1980
Diatom, *Ditylum brightwellii*	Mercuric chloride	5-day EC50 (growth)	10	Canterford & Canterford, 1980
Seaweed, *Fucus serratus*	Mercuric chloride	10-day EC50 (growth)	160	Stromgren, 1980
Seaweed, *Fucus spiralis*	Mercuric chloride	10-day EC50 (growth)	80	Stromgren, 1980
Seaweed, *Fucus vesiculosus*	Mercuric chloride	10-day EC50 (growth)	45	Stromgren, 1980
Giant kelp, *Macrocystis pyrifera*	Mercuric chloride	4-day EC50 (growth)	50	Clendenning & North, 1959
Seaweed, *Pelvetia canaliculata*	Mercuric chloride	10-day EC50 (growth)	130	Stromgren, 1980

* Results are expressed as mercury, not as the chemical.

Table 5. Bioaccumulation of Mercury by Aquatic Organisms

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor[a]	Reference
		FRESHWATER SPECIES			
		Mercury(II)			
Rainbow trout, *Salmo gairdneri*	Whole body	Mercuric chloride	60	1,800	Boudou & Ribeyre, 1984
Fathead minnow, *Pimephales promelas*	Whole body	Mercuric chloride	287	4,994**	Snarski & Olson, 1982
		Methylmercury			
Rainbow trout, *Salmo gairdneri*	Whole body	Methylmercuric chloride	60	11,000	Boudou & Ribeyre, 1984
Rainbow trout, *Salmo gairdneri*	Whole body	Methylmercuric chloride	75	85,700	Niimi & Lowe-Jinde, 1984
Brook trout, *Salvelinus fontinalis*	Muscle	Methylmercuric chloride	273	11,000-33,000	McKim, et al. 1976
Brook trout, *Salvelinus fontinalis*	Whole body	Methylmercuric chloride	273	10,000-23,000	McKim, et al. 1976
Brook trout, *Salvelinus fontinalis*	Muscle and whole body	Methylmercuric chloride	756	12,000	McKim, et al. 1976
Fathead minnow, *Pimephales promelas*	Whole body	Methylmercuric chloride	336	44,130-81,670	Olson, et al. 1975
		SALTWATER SPECIES			
		Mercury(II)			
Eastern oyster (adult), *Crassostrea virginica*	Soft parts	Mercuric chloride	74	10,000	Kopfler, 1974
American lobster (adult), *Homarus americanus*	Tail muscle	Mercuric chloride	30	129	Thurberg, et al. 1977

Table 5. (Continued)

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	Reference
		Methylmercury			
Eastern oyster (adult), *Crassostrea virginica*	Soft parts	Methylmercuric chloride	74	40,000	Kopfler, 1974
		Other Mercury Compounds			
Eastern oyster (adult), *Crassostrea virginica*	Soft parts	Phenylmercuric chloride	74	40,000	Kopfler, 1974

* Results are based on mercury, not the chemical.

**From concentrations that caused adverse effects in a life-cycle test.

Maximum Permissible Tissue Concentration

Consumer	Action Level or Effect	Concentration (mg/kg)	Reference
Man	Action level for edible fish or shellfish	1.0	U.S. FDA, 1984a,b
Mink, *Mustela vison*	Histological evidence of injury	≤1.1	Wobeser, 1976a,b
Brook trout, *Salvelinus fontinalis*	Death (700 days)	5-7	McKim, et al. 1976

Methylmercury

Freshwater Final Residue Value = (1.0 mg/kg) / 81,700 = 0.000012 mg/kg = 0.012 µg/L (see text)

Saltwater Final Residue Value = (1.0 mg/kg) / 40,000 = 0.000025 mg/kg = 0.025 µg/L

Mercury(II)

Freshwater Final Residue Value = (1.0 mg/kg) / 4,994 = 0.00020 mg/kg = 0.20 µg/L (see text)

Saltwater Final Residue Value = (1.0 mg/kg) / 10,000 = 0.00010 mg/kg = 0.10 µg/L (see text)

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

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
			FRESHWATER SPECIES		
			Mercury(II)		
Alga, (Spring assemblages, predominantely diatoms)	Mercuric chloride	2 hrs	EC50 (reduced photosynthesis)	80	Blinn, et al. 1977
Alga, *Ankistrodesmus braunii*	Mercuric chloride	168-240 hrs	EC50 (inhibited lipid biosynthesis)	2,590	Matson, et al. 1972
Alga, *Ankistrodesmus braunii*	Mercuric chloride	24 days	Inhibited growth	74	Trevors, 1982
Alga, *Ankistrodesmus* sp.	Mercuric chloride	10 days	More toxic at pH = 5 than pH = 7	5	Baker, et al. 1983
Alga, *Synedra ulna*	Mercuric chloride	0.29 days	BCF=29,000	-	Fujita & Hashizume, 1972
Green alga, *Scenedesmus quadricauda*	Mercuric chloride	96 hrs	Incipient inhibition	30**	Bringmann & Kuhn, 1959a,b
Green alga, *Scenedesmus quadricauda*	Mercuric cyanide	96 hrs	Incipient inhibition	150**	Bringmann & Kuhn, 1959a,b
Bacteria, *Escherichia coli*	Mercuric chloride	-	Incipient inhibition	200	Bringmann & Kuhn, 1959a
Bacteria, *Escherichia coli*	Mercuric cyanide	-	Incipient inhibition	200	Bringmann & Kuhn, 1959a
Bacteria, *Pseudomonas putida*	Mercuric chloride	16 hrs	Incipient inhibition	10	Bringmann & Kuhn, 1976, 1977a, 1979, 1980b
Protozoan, *Entosiphon sulcatum*	Mercuric chloride	72 hrs	Incipient inhibition	18	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981
Protozoan, *Chilomonas paramecium*	Mercuric chloride	48 hrs	Incipient inhibition	15	Bringmann, et al. 1980; Bringmann & Kuhn, 1981
Protozoan, *Uronema parduczi*	Mercuric chloride	20 hrs	Incipient inhibition	67	Bringmann & Kuhn, 1980a, 1981

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Protozoan, *Microregma heterostoma*	Mercuric chloride	28 hrs	Incipient inhibition	150	Bringmann & Kuhn, 1959b
Protozoan, *Microregma heterostoma*	Mercuric cyanide	28 hrs	Incipient inhibition	160	Bringmann & Kuhn, 1959b
Hydra, *Hydra oligactis*	Mercuric chloride	48 hrs	LC50	56	Slooff, 1983; Slooff, et al. 1983
Planarian, *Dugesia lugubris*	Mercuric chloride	48 hrs	LC50	55	Slooff, 1983
Tubificid worm, *Tubifex tubifex*	Mercuric chloride	48 hrs	LC50	3,200	Qureshi, et al. 1980
Snail, *Lymnaea stagnalis*	Mercuric chloride	48 hrs	LC50	443	Slooff, 1983; Slooff, et al. 1983
Mussel, *Margaritifera margaritifera*	Mercuric nitrate	39 days	BCF=302	-	Mellinger, 1973
Cladoceran, *Diaphanosoma sp.*	Mercuric chloride	3 wks	Reduced population density	2.8	Marshall, et al. 1981
Cladoceran, *Daphnia galeata mendotae*	Mercuric chloride	3 wks	Reduced population density	2.2	Marshall, et al. 1981
Cladoceran, *Daphnia magna*	Mercuric chloride	3 wks	Reproductive impairment	3.4	Biesinger & Christensen, 1972
Cladoceran, *Daphnia magna*	Mercuric chloride	48 hrs	EC50	30**	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	Mercuric cyanide	48 hrs	EC50	20**	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	Mercuric chloride	24 hrs	LC50	13	Bringmann & Kuhn, 1977b
Cladoceran, *Bosmina longirostris*	Mercuric chloride	3 wks	Reduced population density	2.8	Marshall, et al. 1981

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Natural copepod assemblages	Mercuric chloride	7 days	Reduced growth rate	28.3	Borgmann, 1980
Amphipod, *Gammarus* sp.	Mercuric chloride	7 days	BCF=2,500	-	Zubarik & O'Connor, 1978
Amphipod, *Gammarus* sp.	Mercuric nitrate	7 days	BCF=2,500	-	Zubarik & O'Connor, 1978
Crayfish (male, mixed ages), *Faxonella clypeatus*	Mercuric chloride	72 hrs	LC50	200	Heit & Fingerman, 1977
Crayfish (0.2 g), *Faxonella clypeatus*	Mercuric chloride	24 hrs	LC50	1,000	Heit & Fingerman, 1977
Crayfish (1.2 g), *Faxonella clypeatus*	Mercuric chloride	672 hrs	LC50	1,000	Heit & Fingerman, 1977
Crayfish (adult), *Orconectes limosus*	Mercuric chloride	96 hrs	LC60	740	Doyle, et al. 1976
Crayfish (juvenile), *Orconectes limosus*	Mercuric chloride	30 days	LC50 (unfed)	2	Boutet & Chaisemartin, 1973
Crayfish (juvenile), *Orconectes limosus*	Mercuric chloride	30 days	LC50 (fed)	<2	Boutet & Chaisemartin, 1973
Crayfish (male, mixed ages), *Procambarus clarki*	Mercuric chloride	72 hrs	LC50	200	Heit & Fingerman, 1977
Freshwater community (primary producers, herbivores and carnivorous midges)	Mercuric chloride	1 yr	Reduced algal standing stock and diversity; no evidence of effects on midges	0.1	Sigmon, et al. 1977
Mosquito, *Aedes aegypti*	Mercuric chloride	48 hrs	LC50	4,100	Slooff, et al. 1983
Mosquito, *Aedes aegypti*	Mercuric chloride	48 hrs	LC50	776	Slooff, et al. 1983

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Pink salmon (embryo), *Oncorhynchus gorbuscha*	Mercuric sulfate	2 days <time from fertiliza-tion to hatch	EC32 to EC81 (deformity)	5.2	Servizi & Martens, 1978
Pink salmon (pre-eyed embryo), *Oncorhynchus gorbuscha*	Mercuric sulfate	2 days <time from fertiliza-tion to stage	LC100	8.5	Servizi & Martens, 1978
Pink salmon (larva), *Oncorhynchus gorbuscha*	Mercuric sulfate	168 hrs	LC50	140	Servizi & Martens, 1978
Sockeye salmon (embryo), *Oncorhynchus nerka*	Mercuric sulfate	2 days <time from fertiliza-tion to hatch	EC45.6 (deformity)	4.3	Servizi & Martens, 1978
Sockeye salmon (pre-eyed embryo), *Oncorhynchus nerka*	Mercuric sulfate	2 days <time from fertiliza-tion to stage	LC100	9.3	Servizi & Martens, 1978
Sockeye salmon (larva), *Oncorhynchus nerka*	Mercuric sulfate	168 hrs	LC50	290	Servizi & Martens, 1978
Sockeye salmon (juvenile), *Oncorhynchus nerka*	Mercuric sulfate	168 hrs	LC50	190	Servizi & Martens, 1978
Rainbow trout (juvenile), *Salmo gairdneri*	Mercuric chloride	24 hrs	LC50	903	Wobeser, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	Mercuric chloride	2 hrs	Depressed olfactory bulber response	74	Hara, et al. 1976
Rainbow trout (juvenile), *Salmo gairdneri*	Mercuric chloride	-	Growth inhibition	2.1-21	Matida, et al. 1971
Rainbow trout, *Salmo gairdneri*	Mercuric chloride	1 wk	Effected osmo-regulation	100	Lock, et al. 1981
Rainbow trout, *Salmo gairdneri*	Mercuric chloride	80 min	Avoidance threshold	0.2	Black & Birge, 1980
Rainbow trout (embryo, larva), *Salmo gairdneri*	Mercuric chloride	28 days	EC50 (death and deformity)	4.7 5.0	Birge, et al. 1979, 1980

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (embryo, larva), Salmo gairdneri	Mercuric chloride	28 days	EC50 (death and deformity)	<0.1	Birge, et al. 1979, 1980
Rainbow trout (embryo, larva), Salmo gairdneri	Mercuric chloride	28 days	EC10 (death and deformity)	0.9	Birge, et al. 1981
Rainbow trout, Salmo gairdneri	Mercuric chloride	5, 18 mo	Substantial mortality	0.12-0.24	Birge, et al. 1979
Rainbow trout, Salmo gairdneri	Mercuric chloride	48 hrs	LC50	480	Slooff, et al. 1983
Goldfish (embryo, larva), Carassius auratus	Mercuric chloride	7 days	EC50 (death and deformity)	121.9	Birge, 1978; Birge, et al. 1979
Goldfish (embryo, larva), Carassius auratus	Mercuric chloride	7 days	EC50 (death and deformity)	0.7	Birge, 1978; Birge, et al. 1979
Common carp, Cyprinus carpio	Mercuric chloride	60-72 hrs	Reduced hatching success	≥3,000	Huckabee & Griffith, 1974
Fathead minnow, Pimephales promelas	Mercuric chloride	48 hrs	LC50	37	Slooff, et al. 1983
White sucker (adult), Catostomus commersoni	Mercuric chloride	36 min	Blood enzyme (LDH) inhibition 20%	8,000	Christensen, 1972
White sucker (adult), Catostomus commersoni	Mercuric chloride	46 min	Blood enzyme (GOT) inhibition 20%	10,000	Christensen, 1972
Channel catfish (embryo, larva), Ictalurus punctatus	Mercuric chloride	10 days	EC50 (death and deformity)	30	Birge, et al. 1979
Channel catfish (embryo, larva), Ictalurus punctatus	Mercuric chloride	10 days	EC50 (death and deformity)	0.3	Birge, et al. 1979
Channel catfish (embryo, larva), Ictalurus punctatus	Mercuric chloride	-	Increased albinism	0.5	Westerman & Birge, 1978
Channel catfish (embryo, larva), Ictalurus punctatus	Mercuric chloride	10 days	BCF=441-2071	-	Birge, et al. 1979

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Channel catfish (embryo, larva), *Ictalurus punctatus*	Mercuric chloride	10 days	BCF-4.4-353	-	Birge, et al. 1979
Mosquitofish, *Gambusia affinis*	Mercuric chloride	>10 days	LC50	500	Boudou, et al. 1979
Guppy, *Poecilia reticulata*	Mercuric chloride	24 hrs	LC50	13	Hamdy, 1977
Guppy, *Poecilia reticulata*	Mercuric chloride	48 hrs	LC50	303	Slooff, et al. 1983
Bluegill (embryo, larva), *Lepomis macrochirus*	Mercuric chloride	7-8 days	EC50 (death and deformity)	88.7	Birge, et al. 1979
Redear sunfish (embryo, larva), *Lepomis microlophus*	Mercuric chloride	7-8 days	EC50 (death and deformity)	137.2	Birge, et al. 1979
Largemouth bass (embryo, larva), *Micropterus salmoides*	Mercuric chloride	8 days	EC50 (death and deformity)	130 140	Birge, et al. 1978, 1979
Largemouth bass (embryo, larva), *Micropterus salmoides*	Mercuric chloride	8 days	EC50 (death and deformity)	5.3	Birge, et al. 1979
Largemouth bass, *Micropterus salmoides*	-	24 hrs	Affected opercular rhythm	10	Morgan, 1979
Mozambique tilapia, *Tilapia mossambica*	Mercuric nitrate	35 days	Clinical symptoms	310	Panigrahi & Misra, 1980
Mozambique tilapia, *Tilapia mossambica*	Mercuric chloride	48 hrs	LC50	1,000	Menezes & Qasim, 1983
Pig frog (embryo, larva), *Rana grylio*	Mercuric chloride	7 days	EC50 (death and deformity)	67.2	Birge, et al. 1979
River frog (embryo, larva), *Rana heckscheri*	Mercuric chloride	7 days	EC50 (death and deformity)	59.9	Birge, et al. 1979
Leopard frog (embryo, larva), *Rana pipiens*	Mercuric chloride	7 days	EC50 (death and deformity)	7.3	Birge, et al. 1979

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Narrow-mouthed toad (embryo, larva), *Gastrophryne carolinensis*	Mercuric chloride	7 days	EC50 (death and deformity)	1 1.3	Birge, et al. 1978, 1979
Green toad (embryo, larva), *Bufo debilis*	Mercuric chloride	7 days	EC50 (death and deformity)	40.0	Birge, et al. 1979
Fowler's toad (embryo, larva), *Bufo fowleri*	Mercuric chloride	7 days	EC50 (death and deformity)	65.9	Birge, et al. 1979
Red-spotted toad (embryo, larva), *Bufo punctatus*	Mercuric chloride	7 days	EC50 (death and deformity)	36.8	Birge, et al. 1979
Northern cricket frog (embryo, larva), *Acris crepitans*	Mercuric chloride	7 days	EC50 (death and deformity)	10.4	Birge, et al. 1979
Southern gray treefrog (embryo, larva), *Hyla chrysoscelis*	Mercuric chloride	7 days	EC50 (death and deformity)	2.4	Birge, et al. 1979
Spring peeper (embryo, larva), *Hyla crucifer*	Mercuric chloride	7 days	EC50 (death and deformity)	2.8	Birge, et al. 1979
Barking treefrog (embryo, larva), *Hyla gratiosa*	Mercuric chloride	7 days	EC50 (death and deformity)	2.5	Birge, et al. 1979
Squirrel treefrog (embryo, larva), *Hyla squirella*	Mercuric chloride	7 days	EC50 (death and deformity)	2.4	Birge, et al. 1979
Gray treefrog (embryo, larva), *Hyla versicolor*	Mercuric chloride	7 days	EC50 (death and deformity)	2.6	Birge, et al. 1979
African clawed frog, *Xenopus laevis*	Mercuric chloride	11 mos	Substantial mortality	0.16-0.2	Birge, et al. 1978
African clawed frog, *Xenopus laevis*	Mercuric chloride	48 hrs	LC50	74	Slooff & Baerselman, 1980; Slooff, et al. 1983

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Marbled salamander (embryo, larva), <u>Ambystoma opacum</u>	Mercuric chloride	7-8 days	EC50 (death and deformity)	108 107.5	Birge, et al. 1978, 1979
		<u>Methylmercury</u>			
Alga, <u>Ankistrodesmus braunii</u>	Methylmercuric chloride	168-240 hrs	Lipid biosynthesis, >EC50	1,598	Matson, et al. 1972
Alga, <u>Coelastrum microporum</u>	Methylmercuric chloride	-	EC50 (growth inhibition)	>2.4-<4.8	Holderness, et al. 1975
Alga, <u>Scenedesmus obliquus</u>	Methylmercuric chloride	14 days	BCF=2,100 (Maximum by third day)***	-	Havlik, et al. 1979
Alga, <u>Microcystis incerta</u>	Methylmercuric chloride	14 days	BCF=990 (Maximum by third day)***	-	Havlik, et al. 1979
Planarian, <u>Dugesia dorotocephala</u>	Methylmercuric chloride	4 days	LC50	200-500	Best, et al. 1981
Mussel, <u>Margaritifera margaritifera</u>	Methylmercuric chloride	57 days	BCF=2,463	-	Mellinger, 1973
Amphipod, <u>Gammarus</u> sp.	Methylmercuric chloride	7 days	BCF=8,000 (approx.)	-	Zubarik & O'Connor, 1978
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	Methylmercuric chloride	84 days****	BCF=4,530 (whole fish, 5 C)	-	Reinert, et al. 1974
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	Methylmercuric chloride	84 days****	BCF=6,620 (whole fish, 10 C)	-	Reinert, et al. 1974
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	Methylmercuric chloride	84 days****	BCF=8,049 (whole fish, 15 C)	-	Reinert, et al. 1974
Rainbow trout, <u>Salmo gairdneri</u>	Methylmercuric chloride	-	inhibited growth	0.0037-0.037	Matida, et al. 1971
Rainbow trout, <u>Salmo gairdneri</u>	Methylmercuric chloride	14 days	approximate LC80	8	Blanc, 1973

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout, Salmo gairdneri	Methylmercuric chloride	1 wk	Effected osmo-regulation	5	Lock, et al. 1981
Rainbow trout, Salmo gairdneri	Methylmercuric chloride plus inorganic mercury	120 days	Loss of appetite	48 mg/kg in food	Matida, et al. 1971
Rainbow trout (embryo, larva), Salmo gairdneri	-	24 days	EC50 (death and deformity)	5	Birge & Black, 1977
Rainbow trout, Salmo gairdneri	Methylmercuric chloride plus inorganic mercury	269 days	Loss of nervous control	48 mg/kg in food	Matida, et al. 1971
Rainbow trout, Salmo gairdneri	Methylmercuric chloride	30 min	EC50 (Reduced viability of sperm)	1,000	McIntyre, 1973
Brook trout (embryo), Salvelinus fontinalis	Methylmercuric chloride	16-17 days	Decreased enzyme (GOT) activity	0.88	Christensen, 1975
Brook trout (alevin), Salvelinus fontinalis	Methylmercuric chloride	Incubation period + 21 days	Reduced growth	0.7	Christensen, 1975
Brook trout (alevins), Salvelinus fontinalis	Methylmercuric chloride	30 days	Increased enzyme (GOT) activity	0.79	Christensen, 1975
Brook trout (juvenile), Salvelinus fontinalis	Methylmercuric chloride	14 days	Increased blood plasma chloride	2.93	Christensen, et al. 1977
Brook trout, Salvelinus fontinalis	Methylmercuric chloride	8 days	Increased cough frequency	≥3	Drummond, et al. 1974
Common carp, Cyprinus carpio	Methylmercuric chloride	16 days	Reduced protein synthesis	0.05	Sharma & Davis, 1980b
Mosquitofish, Gambusia affinis	Methylmercuric chloride	<24 hrs	LC50	500	Boudou, et al. 1979

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Mosquitofish, *Gambusia affinis*	Methylmercuric chloride	30 days	BCF=2,500 (whole fish, 10 C)	-	Boudou, et al. 1979
Mosquitofish, *Gambusia affinis*	Methylmercuric chloride	30 days	BCF=4,300 (whole fish, 18 C)	-	Boudou, et al. 1979
Mosquitofish, *Gambusia affinis*	Methylmercuric chloride	30 days	BCF=3,000 (whole fish, 164 mg/kg in food, 10 C)	-	Boudou, et al. 1979
Mosquitofish, *Gambusia affinis*	Methylmercuric chloride	30 days	BCF=27,000 (whole fish, 238 mg/kg in food, 26 C)	-	Boudou, et al. 1979
Bluegill (juvenile), *Lepomis macrochirus*	Methylmercuric chloride	28.5 days	BCF=373***** (whole fish, 9 C)	-	Cember, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	Methylmercuric chloride	28.5 days	BCF=921***** (whole fish, 21 C)	-	Cember, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	Methylmercuric chloride	28.5 days	BCF=2,400***** (whole fish, 33 C)	-	Cember, et al. 1978
Leopard frog (tadpole), *Rana pipiens*	Methylmercuric chloride	48 hrs	LC100	50-100	Chang, et al. 1974
Leopard frog, *Rana pipiens*	Methylmercuric chloride	4 mos	Failure to metamorphose	1-10	Chang, et al. 1974
Leopard frog (blastula embryo), *Rana pipiens*	Methylmercuric chloride	5 days	LC50	12-16	Dial, 1976

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Leopard frog (gastrula embryo), *Rana pipiens*	Methylmercuric chloride	5 days	LC50	8-12	Dial, 1976
Leopard frog (neural plate embryo), *Rana pipiens*	Methylmercuric chloride	5 days	LC50	12-16	Dial, 1976
Leopard frog (blastula embryo), *Rana pipiens*	Methylmercuric chloride	96 hrs	EC50 (teratogenesis)	0-4	Dial, 1976
Leopard frog (gastrula embryo), *Rana pipiens*	Methylmercuric chloride	96 hrs	EC50 (teratogenesis)	8-12	Dial, 1976
Leopard frog (neural plate embryo), *Rana pipiens*	Methylmercuric chloride	96 hrs	EC50 (teratogenesis)	12	Dial, 1976
Newt, *Triturus viridescens*	Methylmercuric chloride	≥2 days	Delayed limb regeneration	8	Chang, et al. 1976
Newt, *Triturus viridescens*	Methylmercuric chloride	17 days	Death	300	Chang, et al. 1976
Newt, *Triturus viridescens*	Methylmercuric chloride	8 days	Death	1,000	Chang, et al. 1976
Mink (adult), *Mustela vison*	Methylmercuric chloride	93 days	Histologic evidence of injury	1,100	Wobeser, 1973
Mink (adult), *Mustola vison*	Methylmercuric chloride	93 days	LC50 in brain tissue	11,000	Wobeser, 1973
		Other Mercury Compounds			
Alga, (Florida Lake assemblage)	Methylmercuric dicyandiamide	125 hrs	Reduced biomass	0.8 (approx.)	Harriss, et al. 1970

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Alga, (Florida Lake assemblage)	N-Methylmercuric-1,2,3,6-tetrahydro-3,6-methano-3,4,5,6,7,7,-hexachloro-phthalimide	125 hrs	Reduced biomass	0.3 (approx.)	Harriss, et al. 1970
Alga, Cladophoraceae	Ethylmercuric phosphate	1 hr	Nuisance control	38.6	Burrows & Combs, 1958
Alga, Ulothrichaceae	Ethylmercuric phosphate	1 hr	Nuisance control	38.6	Burrows & Combs, 1958
Alga, (Florida Lake assemblage)	Phenylmercuric acetate	125 hrs	Reduced biomass	0.5 (approx.)	Harriss, et al. 1970
Alga, (Florida Lake assemblage)	Diphenyl mercury	125 hrs	Reduced biomass	2.8 (approx.)	Harriss, et al. 1970
Alga, <u>Scenedesmus obliquus</u>	Phenylmercuric chloride	14 days	BCF=13,000 (Maximum by third day)	-	Havlik, et al. 1979
Alga, <u>Microcystis incerta</u>	Phenylmercuric chloride	14 days	BCF=4,000 (Maximum by third day)	-	Havlik, et al. 1979
Sponge, <u>Ephydatia fluviatilis</u>	Mercury	30 days	Malformed gemmoscleres		Mysing-Gubala & Poirrier, 1981
Sponge, <u>Ephydatia fluviatilis</u>	Mercury	30 days	LC50	100-500	Mysing-Gubala & Poirrier, 1981
Amphipod, <u>Gammarus</u> sp.	Phenylmercuric acetate	7 days	BCF=8,000 (approx.)	-	Zubarik & O'Connor, 1978
Crayfish (juvenile), <u>Procambarus clarki</u>	Methylmercuric dicyandimide	120 hrs	LC50	56	Hendrick & Everett, 1965
Sockeye salmon (juvenile), <u>Oncorhynchus nerka</u>	Pyridylmercuric acetate	1.5 hrs	LC50	10,500-15,700	Burrows & Palmer, 1949
Sockeye salmon (juvenile), <u>Oncorhynchus nerka</u>	Pyridylmercuric acetate	1 hr	Safe for disease control	<954	Rucker, 1948

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Sockeye salmon (juvenile), *Oncorhynchus nerka*	Pyridylmercuric acetate	1 hr	Safe for disease control	<4,752	Rucker & Whipple, 1951
Chinook salmon (fingerling), *Oncorhynchus tshawytscha*	Ethylmercuric phosphate	1 hr	Distress	77	Burrows & Combs, 1958
Chinook salmon, *Oncorhynchus tshawytscha*	Ethylmercuric phopshate	20 hrs	Safe for disease control	39	Burrows & Combs, 1958
Rainbow trout (juvenile), *Salmo gairdneri*	Pyridylmercuric acetate	1 hr	LC100	1,030	Allison, 1957
Rainbow trout (juvenile), *Salmo gairdneri*	Pyridylmercuric acetate	1 hr	LC0	967	Allison, 1957
Rainbow trout (juvenile), *Salmo gairdneri*	Pyridylmercuric acetate	1 hr	LC33 (8.3 C) (13.3 C)	4,750 4,750	Rodgers, et al. 1951
Rainbow trout (alevin), *Salmo gairdneri*	Pyridylmercuric acetate	1 hr	Safe for disease control	<4,750	Rucker & Whipple, 1951
Rainbow trout (juvenile), *Salmo gairdneri*	Pyridylmercuric acetate	1 hr	LC60	517	Allison, 1957
Rainbow trout, *Salmo gairdneri*	Phenylmercuric acetate	12 wks	Growth inhibition	0.11-1.1	Matida, et al. 1971
Rainbow trout (juvenile), *Salmo gairdneri*	Ethylmercuric phosphate	48 hrs	LC50	43	Matida, et al. 1971
Rainbow trout (juvenile), *Salmo gairdneri*	Ethylmercuric p-toluene sulfonanilide	-	Retarded learning	5 µg/g in feed daily or 10 µg/g feed every fifth day	Hartman, 1978
Rainbow trout (juvenile), *Salmo gairdneri*	Pyridylmercuric acetate	24 hrs	LC50	25	MacLeod & Pessah, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	Phenylmercuric acetate	48 hrs	LC50	1,780	Willford, 1966

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	Merthiolate	48 hrs	LC50	10,500	Willford, 1966
Brown trout (juvenile), <u>Salmo trutta</u>	Pyridylmercuric acetate	1 hr	Safe for disease control	4,750	Rodgers, et al. 1951
Brown trout (juvenile), <u>Salmo trutta</u>	Pyridylmercuric acetate	48 hrs	LC50	2,950	Willford, 1966
Brown trout (juvenile), <u>Salmo trutta</u>	Merthiolate	48 hrs	LC50	26,800	Willford, 1966
Brook trout (juvenile), <u>Salvelinus fontinalis</u>	Pyridylmercuric acetate	1 hr	Safe for disease control	2,070	Allison, 1957
Brook trout (juvenile), <u>Salvelinus fontinalis</u>	Pyridylmercuric acetate	1 hr	Safe for disease control	4,750	Rodgers, et al. 1951
Brook trout (juvenile), <u>Salvelinus fontinalis</u>	Pyridylmercuric acetate	48 hrs	LC50	5,080	Willford, 1966
Brook trout (juvenile), <u>Salvelinus fontinalis</u>	Merthiolate	48 hrs	LC50	36,900	Willford, 1966
Lake trout (juvenile), <u>Salvelinus namaycush</u>	Pyridylmercuric acetate	48 hrs	LC50	3,610	Willford, 1966
Lake trout (juvenile), <u>Salvelinus namaycush</u>	Merthiolate	48 hrs	LC50	1,060	Willford, 1966
Channel catfish (juvenile), <u>Ictalurus punctatus</u>	Pyridylmercuric acetate	72 hrs	LC50	232	Clemens & Sneed, 1958a, 1959
Channel catfish (juvenile), <u>Ictalurus punctatus</u>	Pyridylmercuric acetate	48 hrs	LC50 (10 C) (16.5 C) (24 C)	1,960 1,340 234	Clemens & Sneed, 1958b
Channel catfish (yolk sac fry), <u>Ictalurus punctatus</u>	Pyridylmercuric acetate	48 hrs	LC50 (23 C)	178	Clemens & Sneed, 1958b
Channel catfish (1 wk-old), <u>Ictalurus punctatus</u>	Pyridylmercuric acetate	48 hrs	LC50 (23 C)	<148	Clemens & Sneed, 1958b

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Channel catfish, *Ictalurus punctatus*	Pyridylmercuric acetate	48 hrs	LC50	1,370	Willford, 1966
Channel catfish, *Ictalurus punctatus*	Merthiolate	48 hrs	LC50	2,800	Willford, 1966
Bluegill (juvenile), *Lepomis macrochirus*	Pyridylmercuric acetate	48 hrs	LC50	7,600	Willford, 1966
Bluegill (juvenile), *Lepomis macrochirus*	Merthiolate	48 hrs	LC50	32,000	Willford, 1966
Largemouth bass, *Micropterus salmoides*	Mercury	21 days	Threshold of effect opercular rhythm	10	Morgan, 1979
		SALTWATER SPECIES			
		Mercury(II)			
Red alga, *Antithamnion plumula*	Mercuric chloride	30 min	LC50 after 7 days	5,000	Boney & Corner, 1959
Alga, *Chaetoceros glavestonensis*	Mercuric chloride	4 days	About 30% reduction in growth	10	Hannan, et al. 1973b
Alga, *Chaetoceros galvestonensis*	Mercuric chloride	4 days	No growth of culture	100	Hannan, et al. 1973b
Alga, *Chaetoceros galvestonensis*	Mercuric chloride	4 days	BCF=10,920	-	Hannan, et al. 1973b
Alga, *Chroomonas salina*	Mercuric chloride	2 days	BCF=853	-	Parrish & Carr, 1976
Alga, *Cyclotella* sp.	Mercuric chloride	3 days	No growth of culture	100	Hannan & Patouillet, 1972
Alga, *Dunaliella* sp.	Mercuric chloride	-	75% reduction in CO_2	2,500	Mills & Colwell, 1977

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Alga, *Dunaliella tertiolecta*	Mercuric chloride	8 days	About 10% increase in maximum chlorophyll *a* concentration	100	Betz, 1977
Alga, *Dunaliella tertiolecta*	Mercuric chloride	8 days	About 45% increase in maximum chlorophyll *a* concentration	220	Betz, 1977
Diatom, *Nitzchia acicularis*	Mercuric chloride	7 days	Prevented growth	150-200	Mora & Fabregas, 1980
Diatom, *Skeletonema costatum*	Mercuric chloride	15 days	Reduced cell density	0.08	Cloutier-Mantha & Harrison, 1980
Alga, *Dunaliella tertiolecta*	Mercuric chloride	3 days	About 15% reduction in growth	10	Davies, 1976
Alga, *Dunaliella tertiolecta*	Mercuric chloride	8 days	No effect on growth	2	Davies, 1976
Alga, *Isochrysis galbana*	Mercuric chloride	15 days	About 10% reduction in growth	5.1	Davies, 1974
Alga, *Isochrysis galbana*	Mercuric chloride	15 days	About 60% reduction in growth	10.5	Davies, 1974
Alga, *Isochrysis galbana*	Mercuric chloride	28 days	Growth rate recovery to near normal after day 5	10.5	Davies, 1974
Kelp (zoospores, gametophytes, sporophytes), *Laminaria hyperborea*	Mercuric chloride	28 days	Lowest concentration causing growth inhibition	10	Hopkins & Kain, 1971
Kelp (zoospores, gametophytes, sporophytes), *Laminaria hyperborea*	Mercuric chloride	22 hrs	EC50 respiration	about 450	Hopkins & Kain, 1971
Kelp (zoospores, gametophytes, sporophytes), *Laminaria hyperborea*	Mercuric chloride	28 hrs	About 80% reduction in respiration	10,000	Hopkins & Kain, 1971

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Alga, *Phaeodactylum tricornutum*	Mercuric chloride	4 days	About 50% reduction in growth	50	Hannan, et al. 1973b
Alga, *Phaeodactylum tricornutum*	Mercuric chloride	4 days	No growth of culture	120	Hannan, et al. 1973a
Alga, *Phaeodactylum tricornutum*	Mercuric chloride	4 days	BCF=7,120	-	Hannan, et al. 1973b
Red alga (sporling), *Plumaria elegans*	Mercuric chloride	24 hrs	40% reduction in growth over 21 days	120	Boney, 1971
Red alga (sporling), *Plumaria elegans*	Mercuric chloride	1 hr	40% reduction in growth over 21 days	1,000	Boney, 1971
Red alga (sporling), *Plumaria elegans*	Mercuric chloride	18 hrs	LC50 after 7 days	3,170	Boney, et al. 1959
Red alga, *Plumaria elegans*	Mercuric chloride	30 min	LC50 after 7 days	6,700	Boney & Corner, 1959
Red alga, *Polysiphonia lanosa*	Mercuric chloride	30 min	LC50 after 7 days	8,000	Boney & Corner, 1959
Alga (mixed), *Asterionella japonica* plus *Diogenes* sp.	Mercuric chloride	8 days	BCF=3,467	-	Laumond, et al. 1973
5 seaweed species, *Ascophyllum nodosum*, *Fucus spiralis*, *F. versiculosus*, *F. serratus*, *Pelvetia canaliculata*	Mercuric chloride	10 days	10-30% reduction in growth	10	Stromgren, 1980
Algae, (eighteen species)	Mercuric chloride	17 days	Growth inhibition	<5-15	Berland, et al. 1976

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/l)*	Reference
Algae, (eighteen species)	Mercuric chloride	17 days	Death	10-50	Berland, et al. 1976
Algae, (three species)	Mercuric chloride	168 hrs	Depressed growth	30-350	Sick & Windom, 1975
Algae, (three species)	Mercuric chloride	168 hrs	No further bioaccumulation	40	Sick & Windom, 1975
Algae, (three species)	Mercuric chloride	168 hrs	Changes in cell chemistry	30-350	Sick & Windom, 1975
Natural phytoplankton populations	Mercuric chloride	120 hrs	Reduced chlorophyll	6	Hollibaugh, et al. 1980
Natural phytoplankton populations	Mercuric chloride	96 hrs	Reduced biomass	2	Hollibaugh, et al. 1980
Phytoplankton, (Natural assemblages)	Mercuric chloride	21 days	Inhibited growth	1	Thomas, et al. 1977
Protozoan, *Cristigera* sp.	Mercuric chloride	12 hrs	Reduced growth	2.5-5	Gray & Ventilla, 1973
Protozoan, *Euplotes vannus*	Mercuric chloride	48 hrs	Inhibition of reproduction	1,000	Persoone & Uyttersprot, 1975
Sand worm (adult), *Nereis virens*	Mercuric chloride	168 hrs	LC50	60	Eisler & Hennekey, 1977
Sand worm (adult), *Nereis virens*	Mercuric chloride	168 hrs	LC100	125	Eisler & Hennekey, 1977
Polychaete worm (adult), *Ophryotrocha diadema*	Mercuric chloride	96 hrs	LC13	50	Reish & Carr, 1978
Polychaete worm (adult), *Ophryotrocha diadema*	Mercuric chloride	96 hrs	LC60	100	Reish & Carr, 1978
Polychaete worm (adult), *Ophryotrocha diadema*	Mercuric chloride	96 hrs	LC100	500	Reish & Carr, 1978
Polychaete worm, *Ophryotrocha diadema*	Mercuric chloride	48 hrs	LC50	30-100	Parker, 1984

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Blue mussel (larva), *Mytilus edulis*	Mercuric chloride	24 hrs	Abnormal development	32	Okubo & Okubo, 1962
Pacific oyster (larva), *Crassostrea gigas*	Mercuric chloride	24 hrs	Abnormal development	32	Okubo & Okubo, 1962
Eastern oyster (embryo), *Crassostrea virginica*	Mercuric chloride	12 days	LC50	12	Calabrese & Nelson, 1974; Calabrese, et al. 1977
Eastern oyster (embryo), *Crassostrea virginica*	Mercuric chloride	48 hrs	LC0	1	Calabrese, et al. 1973
Eastern oyster (embryo), *Crassostrea virginica*	Mercuric chloride	19 days	Trace metal upset	50	Kopfler, 1974
Clam, *Mulina lateralis*	Mercuric chloride	72 hrs	Reduced calcium uptake	26.5	Ming-Shan & Zubkoff, 1982
Common rangia, *Rangia cuneata*	Mercuric chloride	96 hrs	LC50 (<1 g/kg salinity)	5,100	Olson & Harrel, 1973
Common rangia, *Rangia cuneata*	Mercuric chloride	14 days	BCF=1,130 (whole animal)	-	Dillon & Neff, 1978
Quahog clam (larva), *Mercenaria mercenaria*	Mercuric chloride	8-10 days	LC50	14	Calabrese & Nelson, 1974; Calabrese, et al. 1977
Quahog clam (larva), *Mercenaria mercenaria*	Mercuric chloride	42-48 hrs	LC0	2.5	Calabrese, et al. 1973
Soft-shell clam (adult), *Mya arenaria*	Mercuric chloride	168 hrs	LC0	1	Eisler & Hennekey, 1977
Soft-shell clam (adult), *Mya arenaria*	Mercuric chloride	168 hrs	LC50	4	Eisler & Hennekey, 1977
Soft-shell clam (adult), *Mya arenaria*	Mercuric chloride	168 hrs	LC100	30	Eisler & Hennekey, 1977
Copepods (adult), (5 genera)	Mercuric chloride	10 days	90% decrease in egg production	10	Reeve, et al. 1977
Copepods (adult), (5 genera)	Mercuric chloride	10 days	70% decrease in fecal pellet	10	Reeve, et al. 1977

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Copepods (adult), (5 genera)	Mercuric chloride	48 hrs	Hg-Cu interactions on LC50	17 (Hg in mixture)	Reeve, et al. 1977
Copepod (adult), Pseudocalanus minutus	Mercuric chloride	70 days	No growth of culture	5	Sonntag & Greve, 1977
Copepod (adult), Pseudocalanus minutus	Mercuric chloride	70 days	No growth inhibition	1	Sonntag & Greve, 1977
Copepod (adult), Acartia clausi	Mercuric chloride	1.9 hrs	LC50	50	Corner & Sparrow, 1956
Copepod (adult), Acartia clausi	Mercuric chloride	24 hrs	BCF=7,500	-	Reiichiro, et al. 1983
Barnacle (adult), Balanus balanoides	Mercuric chloride	48 hrs	LC90	1,000	Clarke, 1947
Barnacle (cyprid), Balanus balanoides	Mercuric chloride	6 hrs	About 10% reduciton in substrate attachment over 19 days	10	Pyefinch & Mott, 1948
Barnacle (cyprid), Balanus balanoides	Mercuric chloride	6 hrs	LC50	90	Pyefinch & Mott, 1948
Barnacles (nauplius), Balanus crenatus	Mercuric chloride	6 hrs	LC50	60	Pyefinch & Mott, 1948
Barnacle (cyprid), Balanus improvisus	Mercuric chloride	48 hrs	About 50% abnormal development	16,600	Clarke, 1947
White shrimp (adult), Penaeus setiferus	Mercuric chloride	60 days	No effect on respiration, growth, or molting	1	Green, et al. 1976
Grass shrimp (larva), Palaemonetes vulgaris	Mercuric chloride	<24 hrs	LC100	56	Shealy & Sandifer, 1975
Grass shrimp (larva), Palaemonetes vulgaris	Mercuric chloride	48 hrs	LC0	<5.6	Shealy & Sandifer, 1975
Grass shrimp, Palaemonetes pugio	Mercuric chloride	120 hrs	LC50	148	Barthalmus, 1977

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Grass shrimp, *Palaemonetes pugio*	Mercuric chloride	24 hrs	Impaired conditioned avoidance response	37	Barthalmus, 1977
Grass shrimp (larva), *Palaemonetes vulgaris*	Mercuric chloride	48 hrs	LC50	10	Shealy & Sandifer, 1975
Grass shrimp (larva), *Palaemonetes vulgaris*	Mercuric chloride	48 hrs	Abnormal development	10-18	Shealy & Sandifer, 1975
Hermit crab (adult), *Pagurus longicarpus*	Mercuric chloride	168 hrs	LC0	10	Eisler & Hennekey, 1977
Hermit crab (adult), *Pagurus longicarpus*	Mercuric chloride	168 hrs	LC50	50	Eisler & Hennekey, 1977
Hermit crab (adult), *Pagurus longicarpus*	Mercuric chloride	168 hrs	LC100	125	Eisler & Hennekey, 1977
Green crab (adult), *Carcinus maenas*	Mercuric chloride	48 hrs	LC50	1,000	Portmann, 1968
Green crab (adult), *Carcinus maenas*	Mercuric chloride	48 hrs	LC50	1,200	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	47 hrs	LC50	10	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	20-30 hrs	LC50	33	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	4.3-13.5 hrs	LC50	100	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	2.7 hrs	LC50	1,000	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	0.5 hrs	LC50	3,300	Connor, 1972
Green crab (larva), *Carcinus maenas*	Mercuric chloride	0.22 hrs	LC50	10,000	Connor, 1972

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Fiddler crab (adult), *Uca pugilator*	Mercuric chloride	28 days	Low survival, inhibited limb regeneration	1,000	Weis, 1976
Fiddler crab (adult), *Uca pugilator*	Mercuric chloride	6 days	20-25% reduction in percent survival	180	Vernberg & Vernberg, 1972
Fiddler crab (adult), *Uca pugilator*	Mercuric chloride	6 days	20-25% reduction in percent survival	180	Vernberg & Vernberg, 1972
Fiddler crab (adult), *Uca pugilator*	Mercuric chloride	24 hrs	Increased oxygen consumption	180	Vernberg & Vernberg, 1972
Fiddler crab (zoea), *Uca pugilator*	Mercuric chloride	8 days	LC50	1.8	DeCoursey & Vernberg, 1972
Fiddler crab (zoea), *Uca pugilator*	Mercuric chloride	24 hrs	20-100% increase in metabolic rate after stage I zoea	1.8	DeCoursey & Vernberg, 1972
Fiddler crab (zoea), *Uca pugilator*	Mercuric chloride	5 days	About 40% increase in swimming activity of stage V zoea	1.8	DeCoursey & Vernberg, 1972
Starfish (adult), *Asterias forbesi*	Mercuric chloride	168 hrs	LC0	10	Eisler & Hennekey, 1977
Starfish (adult), *Asterias forbesi*	Mercuric chloride	168 hrs	LC50	20	Eisler & Hennekey, 1977
Starfish (adult), *Asterias forbesi*	Mercuric chloride	168 hrs	LC100	125	Eisler & Hennekey, 1977
Sea urchin (spermatazoa), *Arbacia punctulata*	Mercuric chloride	8 min	About 150% increase in swimming speed	20	Young & Nelson, 1974
Sea urchin (spermatazoa), *Arbacia punctulata*	Mercuric chloride	24 min	About 80% decrease in swimming speed	2,000	Young & Nelson, 1974
Sea urchin (embryo), *Arbacia punctulata*	Mercuric chloride	13 hrs	Abnormal development	92	Waterman, 1937
Haddock (embryo), *Melanogrammus aeglefinus*	Mercuric chloride	96 hrs	LC50	918	Cardin, 1982

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	168 hrs	LC0	100	Eisler & Hennekey, 1977
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	168 hrs	LC50	800	Eisler & Hennekey, 1977
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	168 hrs	LC100	1,000	Eisler & Hennekey, 1977
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	24 hrs	Disrupted osmoregulation	125	Renfro, et al. 1974
Mummichog (adult), Fundulus heteroclitus	-	96 hrs	Affected liver enzymes	200	Jackim, et al. 1970
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	28 days	Up to 40% reduction in enzyme activity before recovery	12	Jackim, 1973
Mummichog (embryo), Fundulus heteroclitus	Mercuric chloride	3 days	Many developmental abnormalities	30-40	Weis & Weis, 1977
Mummichog (embryo), Fundulus heteroclitus	Mercuric chloride	3 days	Some developmental abnormalities	10-20	Weis & Weis, 1977
Mummichog (embryo), Fundulus heteroclitus	Mercuric chloride	12 hrs	Some developmental abnormalities	30-40	Weis & Weis, 1977
Mummichog (embryo), Fundulus heteroclitus	Mercuric chloride	32 days	EC50	67.4	Sharp & Neff, 1980
Mummichog (larva), Fundulus heteroclitus	Mercuric chloride	-	No effect	50	Weis & Weis, 1983
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	-	Mercury redistribution organs following Se pretreatment	1,000 ug Hg/ kg body wt plus 400 ug Se/kd body wt	Sheline & Schmidt-Nielson, 1977
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	96 hrs	Cellular degeneration	250-5,000	Gardner, 1975
Mummichog (adult), Fundulus heteroclitus	Mercuric chloride	48 hrs	LC100	2,000	Eisler, et al. 1972

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)[a]	Reference
Mummichog (adult), *Fundulus heteroclitus*	Mercuric chloride	96 hrs	Sluggish, uncoordinated swimming	1,150	Klaunig, et al. 1975
Shiner perch, *Cymatogaster aggregata*	Mercuric chloride	-	45% reduction of brain cholinesterase activity	33,900	Abou-Donia & Menzel, 1967
Striped bass (adult), *Morone saxatilis*	Mercuric chloride	30 days	Decreased respiration 30 days post exposure	5	Dawson, et al. 1977
Winter flounder (adult), *Pseudopleuronectes americanus*	Mercuric chloride	60 days	Decreased respiration	10	Calabrese, et al. 1975
		Methylmercury			
Alga, *Dunaliella tertiolecta*	Methylmercuric chloride	10 min	EC50 (photosynthesis)	about 170	Overnell, 1975
Alga, *Phaeodactylum tricornutum*	Methylmercuric chloride	25 days	EC50 (photosynthesis)	about 190	Overnell, 1975
Red alga (sporling), *Plumaria elegans*	Methylmercuric chloride	18 hrs	LC50 after 7 days	44	Boney, et al. 1959
Alga, *Tetraselmis succica*	Methylmercuric chloride	3 days	Inhibited growth	25	Mora & Fabregas, 1980
Alga, *Chaetoceros* sp.	Dimethylmercury	3 days	About 75% reduction in growth	100	Hannan & Patouillet, 1972
Alga, *Cyclotella* sp.	Dimethylmercury	3 days	About 15% reduction in growth	500	Hannan & Patouillet, 1972
Alga, *Phaeodactylum* sp.	Dimethylmercury	3 days	About 45% reduction in growth	500	Hannan & Patouillet, 1972
Red alga (sporling), *Plumaria elegans*	Methylmercuric chloride	25 min	EC50 (growth over 21 days	40	Boney, 1971
Diatom, *Nitzchia acicularis*	Methylmercuric chloride	3 days	Inhibited growth	25	Mora & Fabregas, 1980

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Dinoflagellate, *Scrippsiella faeroense*	Mercuric acetate	14 days	No growth of culture	1,000	Kayser, 1976
Alga, *Chlorella* sp.	Ethylmercuric phosphate	10 days	22% reduction in growth	0.6	Ukeles, 1962
Alga, *Chlorella* sp.	Ethylmercuric phosphate	10 days	100% lethal to culture	6	Ukeles, 1962
Alga, *Dunaliella euchlora*	Ethylmercuric phosphate	10 days	36% reduction in growth	0.6	Ukeles, 1962
Alga, *Dunaliella euchlora*	Ethylmercuric phosphate	10 days	100% lethal to culture	60	Ukeles, 1962
Alga, *Monochrysis lutheri*	Ethylmercuric phosphate	10 days	No reduction in growth	0.6	Ukeles, 1962
Alga, *Monochrysis lutheri*	Ethylmercuric phosphate	10 days	100% lethal to culture	6	Ukeles, 1962
Alga, *Phaeodactylum tricornutum*	Ethylmercuric phosphate	10 days	45% reduction in growth	0.6	Ukeles, 1962
Alga, *Phaeodactylum tricornutum*	Ethylmercuric phosphate	10 days	100% lethal to culture	6	Ukeles, 1962
Alga, *Protococcus* sp.	Ethylmercuric phosphate	10 days	14% reduction in growth	0.6	Ukeles, 1962
Alga, *Protococcus* sp.	Ethylmercuric phosphate	10 days	100% lethal to culture	6	Ukeles, 1962
Red alga (sporling), *Plumaria elegans*	Mercuric iodide	18 hrs	LC50 after 7 days	156	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	Ethylmercuric chloride	18 hrs	LC50 after 7 days	26	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	Phenylmercuric chloride	18 hrs	LC50 after 7 days	54	Boney, et al. 1959

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Diatom, *Nitzchia delicatissima*	Methylmercuric dicyandiamide	24 hrs	EC50 (photosynthesis)	0.4	Harriss, et al. 1970
Blue mussel (adult), *Mytilus edulis*	Methylmercuric chloride	24 hrs	About 90% reduced feeding rate	400	Dorn, 1976
Eastern oyster (adult), *Crassostrea virginica*	Methylmercuric chloride	19 days	Trace metal upset	50	Kopfler, 1974
Copepod (adult), *Acartia clausi*	Methylmercuric chloride	24 hrs	BCF=56,000-350,000	-	Reichiro, et al. 1983
Amphipod (adult), *Gammarus duebeni*	Methylmercuric chloride	3 days	Induced diuresis	56	Lockwood & Inman, 1975
Fiddler crab (adult), *Uca* sp.	Methylmercuric chloride	32 days	No limb regeneration	300-500	Weis, 1977
Fiddler crab (adult), *Uca* sp.	Methylmercuric chloride	32 days	Melanin absent in regerated limbs	100	Weis, 1977
Mummichog (adult), *Fundulus heteroclitus*	Methylmercuric chloride	24 hrs	Disrupted osmoregulation	125	Renfro, et al. 1974
Mummichog (embryo), *Fundulus heteroclitus*	Methylmercuric chloride	7 days	Teratological effects	50	Weis, et al. 1981
Mummichog (larva), *Fundulus heteroclitus*	Methylmercuric chloride	-	Reduced LT50s	50	Weis & Weis, 1983
Mummichog (embryo), *Fundulus heteroclitus*	Methylmercuric chloride	-	Developed resistance in a pond	50	Weis & Weis, 1984
Striped mullet, *Mugil cephalus*	Methylmercuric chloride	13 days	Inhibited fin regeneration	1	Weis & Weis, 1978
		Other Mercury Compounds			
Dinoflagellate, *Gymnodinium spendens*	Mercuric acetate	11 days	55% reduction in growth	10	Kayser, 1976
Dinoflagellate, *Scrippsiella faeroense*	Mercuric acetate	25 days	45% reduction in growth, morphological variation	10	Kayser, 1976

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Red alga (sporling), *Plumaria elegans*	Phenylmercuric iodide	18 hrs	LC50 after 7 days	104	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	Isoamylmercuric chloride	18 hrs	LC50 after 7 days	19	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	n-amylmercuric chloride	18 hrs	LC50 after 7 days	13	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	Isopropylmercuric chloride	18 hrs	LC50 after 7 days	28	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	n-propylmercuric chloride	18 hrs	LC50 after 7 days	13	Boney, et al. 1959
Red alga (sporling), *Plumaria elegans*	n-butylmercuric chloride	18 hrs	LC50 after 7 days	13	Boney, et al. 1959
Diatom, *Nitzchia delicatissima*	N-methylmercuric-1,2,3,6-tetrahydro-3,6-methano-3,4,5,6,7,7-hexachloro-phthalimine	24 hrs	EC50 (photosynthesis)	0.3	Harriss, et al. 1970
Diatom, *Nitzchia delicatissima*	Phenylmercuric acetate	24 hrs	EC50 (photosynthesis)	1.5	Harriss, et al. 1970
Diatom, *Nitzchia delicatissima*	Diphenylmercury	24 hrs	EC50 (photosynthesis)	18	Harriss, et al. 1970
Diatom, *Nitzchia acicularis*	Phenylmercuric acetate	7 days	Inhibited growth	25	Mora & Fabregas, 1980
Eastern oyster (adult), *Crassostrea virginica*	Mercuric acetate	12 hrs daily for 15 days	33% reduction in shell growth	10	Cunningham, 1976
Eastern oyster (adult), *Crassostrea virginica*	Mercuric acetate	60 days	LC55	100	Cunningham, 1976
Eastern oyster (adult), *Crassostrea virginica*	Phenylmercuric chloride	19 days	Trace metal upset	50	Kopfler, 1974

Table 6. (Continued)

Species	Chemical	Duration	Effect	Result (µg/L)*	Reference
Copepod (adult), *Acartia clausi*	Mercuric acetate	1.9 hrs	LC50	50	Corner & Sparrow, 1956
Copepod (adult), *Acartia clausi*	Ethylmercuric chloride	1.9 hrs	LC50	50	Corner & Sparrow, 1956
Coho salmon (adult), *Oncorhynchus kisutch*	Pyridylmercuric acetate	12-15 wks, 1 hr wkly as juveniles	0.03 mg Hg/kg wet wt muscle 2 yrs post-exposure	1,000	Amend, 1970
Sockeye salmon (juvenile), *Oncorhynchus nerka*	Pyridylmercuric acetate	12-15 wks, 1 hr wkly	1.2 mg Hg/kg wet wt muscle 12 weeks post-exposure	1,000	Amend, 1970
Sockeye salmon (adult), *Oncorhynchus nerka*	Pyridylmercuric acetate	12-15 wks, 1 hr wkly as juveniles	0.24 mg Hg/kg wet wt muscle 3 yrs post-exposure	1,000	Amend, 1970
Sockeye salmon (adult), *Oncorhynchus nerka*	Pyridylmercuric acetate	12 1-hr exposures as juveniles	0.04 mg Hg/kg wet wt muscle 4 yrs post-exposure	1,000	Amend, 1970
Chinook salmon (adult), *Oncorhynchus tshawytscha*	Pyridylmercuric acetate	35 wks, 1 hr wkly as juveniles	up to 0.12 mg Hg/kg muscle 4 yrs later	1,000	Amend, 1970
Threespine stickleback, *Gasterosteus aculeatus*	Phenylmercuric acetate	370 min	LC100	100	Boetius, 1960

* Results are expressed as mercury, not as the chemical.

** In river water.

*** Static, continual loss over time.

**** Not at steady-state.

*****BCF independent of concentration in water over range tested.

REFERENCES

Abernathy, A.R. and P.M. Cumbie. 1977. Mercury accumulation by largemouth bass (*Micropterus salmoides*) in recently impounded reservoirs. Bull. Environ. Contam. Toxicol. 17: 595.

Abou-Donia, M.B. and D.B. Menzel. 1967. Fish brain cholinesterase--its inhibition by carbamates and automatic assay. Comp. Biochem. Physiol. 21: 99.

Ahsanullah, M. 1982. Acute toxicity of chromium, mercury, molybdenum and nickel to the amphipod *Allorchestes compressa*. Aust. Jour. Mar. Freshwater Res. 33: 465.

Akagi, H., et al. 1979. Mercury methylation and partition in aquatic systems. Bull. Environ. Contam. Toxicol. 23: 372.

Akielaszek, J.J. and T.A. Haines. 1981. Mercury in the muscle tissue of fish from three northern Maine lakes. Bull. Environ. Contam. Toxicol. 27: 201.

Akiyama, A. 1970. Acute toxicity of two organic mercury compounds to the teleost, *Oryzias latipes*, in different stages of development. Bull. Jap. Soc. Sci. Fish. 36: 563.

Albanus, L., et al. 1972. Toxicity for cats of methylmercury in contaminated fish from Swedish lakes and of methylmercury hydroxide added to fish. Environ. Res. 5: 425.

Alexander, J., et al. 1979. The influence of selenium on methyl mercury toxicity in rat hepatoma cells, human embryonic fibroblasts and human lymphocytes in culture. Acta Pharmacol. Toxicol. 45: 379.

Allison, L.M. 1957. Variation in strength of pyridylmercuric acetate technical and its effect on rainbow trout. Prog. Fish-Cult. 19: 108.

Amend, D.F. 1970. Retention of mercury by salmon. Prog. Fish-Cult. 32: 192.

Amend, D.F., et al. 1969. Some factors influencing susceptibility of rainbow trout to the acute toxicity of an ethyl mercury phosphate formulation (Timsan). Trans. Am. Fish. Soc. 98: 419.

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.

Applegate, V.C., et al. 1957. Toxicity of 4,346 chemicals to larval lampreys and fishes. Special Scientific Report -- Fisheries No. 207. U.S. Fish and Wildlife Service, Washington, D.C.

Armstrong, F.A.J. and D.P. Scott. 1979. Decrease in mercury content of fishes in Ball Lake, Ontario, since imposition of controls on mercury discharges. Jour. Fish. Res. Board Can. 36: 670.

Bache, C.A., et al. 1971. Residues of total mercury and methylmercury salts in lake trout as a function of age. Science 172: 951.

Baker, D.H. 1973. Mercury: uptake by the goldfish, Carassius auratus, from low concentrations in water and its tissue distribution. PB 227462. National Technical Information Service, Springfield, Virginia.

Baker, M.D., et al. 1983. Toxicity of pH, heavy metals and bisulfite to a freshwater green algae. Chemosphere 12: 35.

Baluja, G., et al. 1983. Mercury distribution in an ecosystem of the "Parque Nacional de Donana," Spain. Bull. Environ. Contam. Toxicol. 30: 544.

Barera, Y. and W.J. Adams. 1983. Resolving some practical questions about Daphnia acute toxicity tests. In: W.E. Bisnop, et al. (eds.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 509.

Barthalmus, G.T. 1977. Behavioral effects of mercury on grass shrimp. Mar. Pollut. Bull. 8: 87.

Beijer, K. and A. Jernelov. 1978. Ecological aspects of mercury-selenium interactions in the marine environment. Environ. Health Perspect. 25: 43.

Beijer, K. and A. Jernelov. 1979. Methylation of mercury in aquatic environments. In: J.O. Nriagu (ed.), The Biogeochemistry of Mercury in the Environment. Elsevier, New York. p. 203.

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

Berland, B.R., et al. 1976. Action toxique de quatre metaux lourds sur la croissance d'algues unicellulaires marines. C.R. Acad. Sci. Paris, t. 282, Ser. D: 633.

Berlin, M. 1978. Interaction between selenium and inorganic mercury. Environ. Health Perspect. 25: 67.

Best, J.B., et al. 1981. Acute toxic responses of the freshwater planarian, Dugesia dorotecephala, to methylmercury. Bull. Environ. Contam. Toxicol. 27: 49.

Betz, M. 1977. Investigations on the simulataneous uptake and release of mercury by Dunaliella tertiolecta. Mar. Biol. 41: 89.

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., et al. 1982. Chronic effects of inorganic and organic mercury on *Daphnia magna*: toxicity, accumulation, and loss. Arch. Environ. Contam. Toxicol. 11: 769.

Bills, T.D., et al. 1977. Effects of residues of the polychlorinated biphenyl Aroclor 1254 on the sensitivity of rainbow trout to selected environmental contaminants. Prog. Fish-Cult. 39: 150.

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. and J.A. Black. 1977. A continuous flow system using fish and amphibian eggs for bioassay determinations on embryonic mortality and teratogenesis. EPA-560/5-77-002. National Technical Information Service, Springfield, Virginia.

Birge, W.J., et al. 1978. Embryo-larval bioassays 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. 9

Birge, W.J., et al. 1979. The effects of mercury on reproduction of fish and amphibians. *In*: J.O. Nriagu (ed.), The Biogeochemistry of Mercury in the Environment. Elsevier, 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. I. Academic Press, New York. p. 59.

Bisogni, J.J., Jr. 1979. Kinetics of methylmercury formation and decomposition in aquatic environments. In: J.O. Nriagu (ed.), The Biogeochemistry of Mercury in the Environment. Elsevier, New York. p. 211.

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

Blanc, J. 1973. Genetic aspects of resistance to mercury poisoning in steelhead trout (*Salmo gairdneri*). M.S. Thesis. Oregon State University, Corvallis, Oregon.

Blinn, D.W., et al. 1977. Mercury inhibition of primary productivity using large volume plastic chambers *in situ*. Jour. Phycol. 13: 58.

Bodaly, R.A., et al. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River Diversion, Northern Manitoba. Can. Jour. Fish. Aquat. Sci. 41: 682.

Boetius, J. 1960. Lethal action of mercuric chloride and phenylmercuric acetate on fishes. Medd. Komm. Havundersog., Kbh. 3: 93.

Boney, A.D. 1971. Sub-lethal effects of mercury on marine algae. Mar. Pollut. Bull. 2: 69.

Boney, A.D. and E.D.S. Corner. 1959. Application of toxic agents in the study of the ecological resistance of intertidal red algae. Jour. Mar. Biol. Assoc. U.K. 38: 267.

Boney, A.D., et al. 1959. The effects of various poisons on the growth and viability of sporelings of the red alga Plumaria elegans (Bonnem.). Biochem. Pharmacol. 2: 37.

Borgmann, U. 1980. Interactive effects of metals in mixtures on biomass production kinetics of freshwater copepods. Can. Jour. Fish. Aquat. Sci. 37: 1295.

Boudou, A. and F. Ribeyre. 1981. Comparative study of the trophic transfer of two mercury compounds - $HgCl_2$ and CH_3HgCl - between Chlorella vulgaris and Daphnia magna. Influence of temperature. Bull. Environ. Contam. Toxicol. 27: 624.

Boudou, A. and F. Ribeyre. 1984. Influence of exposure length on the direct bioaccumulation of two mercury compounds by Salmo gairdneri (fry) and the relationship between organism weight and mercury concentrations. Water Res. 18: 81.

Boudou, A., et al. 1977. Modeles experimentaux en ecotoxicologie: chaines trophiques en milieu limnique. Bull. Ecol. 8: 401.

Boudou, A., et al. 1979. Bioaccumulation and bioamplification of mercury compounds in a second level consumer, Gambusia affinis--temperature effects. Bull. Environ. Contam. Toxicol. 22: 813.

Boudou, A., et al. 1980. Bioaccumulation et bioamplification des derives du mercure par un consommateur de troisieme ordre: Salmo gairdneri - incidences du facteur temperature. Water Res. 14: 61.

Bouquegneau, J.M. 1979. Evidence for the protective effect of metallothioneins against inorganic mercury injuries to fish. Bull. Environ. Contam. Toxicol. 23: 218.

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.

Bowers, M.A., et al. 1980. Failure of selenite to protect against mercuric chloride in early developmental stages of the Japanese ricefish (Oryzias latipes). Comp. Biochem. Physiol. 66C: 175.

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 the 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 tests. 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.

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

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.

Burrows, R.E. and B.D. Combs. 1958. Lignasan as bactericide and algaecide. Prog. Fish-Cult. 20: 143.

Burrows, R.E. and D.D. Palmer. 1949. Pyridylmercuric acetate: its toxicity to fish, efficacy in disease control, and applicability to a simplified treatment technique. Prog. Fish-Cult. 11: 147.

Burrows, W.D. and P.A. Krenkel. 1973. Studies on uptake and loss of methylmercury-203 by bluegills (_Lepomis macrochirus_ Raf.). Environ. Sci. Technol. 7: 1127.

Burrows, W.D., et al. 1974. The uptake and loss of methylmercury by freshwater fish. I. Congreso Internacional del Mercúrio, Barcelona. Tomo II. 283.

Busch, W.N. 1983. Decline of mercury in young fishes from western Lake Erie between 1970-71 and 1974. Prog. Fish-Cult. 45: 202.

Calabrese, A. and D.A. Nelson. 1974. Inhibition of embryonic development of the hard clam, Mercenaria mercenaria, by heavy metals. Bull. Environ. Contam. Toxicol. 11: 92.

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 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.

Calabrese, A., et al. 1977. Survival and growth of bivalve larvae under heavy-metal stress. Mar. Biol. 41: 179.

Call, D.J., et al. 1983. Toxicity and metabolism studies with EPA priority pollutants and related chemicals in freshwater organisms. PB83-263665. National Technical Information Service, Springfield, Virginia.

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.

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

Cappon, C.J. 1984. Content and chemical form of mercury and selenium in Lake Ontario salmon and trout. Jour. Great Lakes Res. 10: 429.

Cappon, C.J. and J.C. Smith. 1982a. Chemical form and distribution of mercury and selenium in canned tuna. Jour. Appl. Toxicol. 2: 181.

Cappon, C.J. and J.C. Smith. 1982b. Chemical form and distribution of mercury and selenium in edible seafood. Jour. Anal. Toxicol. 6: 10.

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

Carter, J.W. and I.L. Cameron. 1973. Toxicity bioassay of heavy metals in water using Tetrahymena pyriformis. Water Res. 7: 951.

Cember, H., et al. 1978. Mercury bioconcentration in fish: temperature and concentration effects. Environ. Pollut. 17: 311.

Chang, L.W., et al. 1974. Effects of methylmercury chloride on Rana pipiens tadpoles. Environ. Res. 8: 82.

Chang, L.W., et al. 1976. Dose-dependent effects of methylmercury on limb regeneration of newts (Tricurus viridescens). Environ. Res. 11: 305.

Chang, P.S.S., et al. 1983. The effects of low pH, selenium and calcium on the bioaccumulation of ^{203}Hg by seven tissues of the crayfish, Orconectes virilis. In: N.K. Kaushik and K.R. Solomon (eds.), Proceedings of the Eighth Annual Aquatic Toxicity Workshop. Can. Tech. Rept. Fish. Aquat. Sci. No. 1151. Dept. of Fisheries and Oceans, Ottawa, Ontario, Canada. p. 45.

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

Chapman, P.M., et al. 1982b. *Effects of species interactions on the survival* and respiration of Limnodrilus hoffmeisteri and Tubifex tubifex (Oligochaeta, Tubificidae) exposed to various pollutants and environmental factors. Water Res. 16: 1405.

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

Charbonneau, S.M., et al. 1974. Subacute toxicity of methylmercury in the adult cat. Toxicol. Appl. Pharmacol. 27: 569.

Christensen, G.M. 1972. Effects of metal cations and other chemicals upon the in vitro activity of two enzymes in the blood plasma of the white sucker, Catostomus commersoni (Lacepede). Chem.-Biol. Interactions 4: 351.

Christensen, G.M. 1975. Biochemical effects of methylmercuric chloride, cadmium chloride, and lead nitrate on embryos and alevins of the brook trout, *Salvelinus fontinalis*. Toxicol. Appl. Pharmacol. 32: 191.

Christensen, G., et al. 1977. The effect of methylmercuric chloride, cadmium chloride, and lead nitrate on six biochemical factors of the brook trout (*Salvelinus fontinalis*). Toxicol. Appl. Pharmacol. 42: 523.

Clarke, G.L. 1947. Poisoning and recovery in barnacles and mussels. Biol. Bull. 92: 73.

Clemens, H.P. and K.E. Sneed. 1958a. The chemical control of some diseases and parasites of channel catfish. Prog. Fish-Cult. 20: 8.

Clemens, H.P. and K.E. Sneed. 1958b. Effect of temperature and physiological condition on tolerance of channel catfish to pyridylmercuric acetate (PMA). Prog. Fish-Cult. 20: 147.

Clemens, H.P. and K.E. Sneed. 1959. Lethal doses of several commercial chemicals for fingerling channel catfish. Special Scientific Report - Fisheries No. 316. U.S. Fish and Wildlife Service, Washington, D.C.

Clendenning, K.A. and W.J. North. 1959. Effects of wastes on the giant kelp, *Macrocystic pyrifera*. *In*: E.A. Pearson (ed.), Proc. 1st Conf. Waste Disposal Marine Environ. Berkely, California. p. 82.

Cloutier-Mantha, L. and P.J. Harrison. 1980. Effects of sublethal concentrations of mercuric chloride on ammonium-limited Skeletonema costatum. Mar. Biol. 56: 219.

Connor, P.M. 1972. Acute toxicity of heavy metals to some marine larvae. Mar. Pollut. Bull. 3: 190.

Copeland, R.A. and J.C. Ayers. 1972. Trace element distributions in water, sediment, phytoplankton, zooplankton and benthos of Lake Michigan: a baseline study with calculations of concentration factors and buildup of radioisotopes in the food web. Special Report No. 1. Environmental Research Group, Inc.

Corner, E.D.S. and B.W. Sparrow. 1956. The modes of action of toxic agents. I. observations on the poisoning of certain crustaceans by copper and mercury. Jour. Mar. Biol. Assoc. U.K. 35: 531.

Cunningham, P.A. 1976. Inhibition of shell growth in the presence of mercury and subsequent recovery of juvenile oysters. Proc. Natl. Shellfish. Assoc. 66: 1.

Cunningham, P.A. and M.R. Tripp. 1973. Accumulation and depuration of mercury in the American oyster Crassostrea virginica. Mar. Biol. 20: 14.

Cunningham, P.A. and M.R. Tripp. 1975. Accumulation, tissue distribution and elimination of $^{203}HgCl_2$ and $CH_3{}^{203}HgCl$ in the tissues of the American oyster Crassostrea virginica. Mar. Biol. 31: 321.

Curtis, M.W. and C.H. Ward. 1981. Aquatic toxicity of forty industrial chemicals: testing in support of hazardous substance spill prevention regulation. Jour. Hydrol. 51: 359.

Curtis, M.W., et al. 1979. Acute toxicity of 12 industrial chemicals to freshwater and saltwater organisms. Water Res. 13: 137.

Czuba, M. and D.C. Mortimer. 1980. Stability of methylmercury and inorganic mercury in aquatic plants (Elodea densa). Can. Jour. Bot. 58: 316.

Daoust, P. 1981. Acute pathological effects of mercury, cadmium and copper in rainbow trout. Ph.D. Thesis. University of Saskatchewan, Saskatoon, Canada.

Das, A.K. and B.N. Misra. 1982. Toxicity of MEMC (2-methoxy ethyl mercuric chloride) an organomercurial fungicide to fish, Cyprinus carpio (L.). Jour. Environ. Biol. 3: 19.

Davies, A.G. 1974. The growth kinetics of Isochrysis galbana in cultures containing sublethal concentrations of mercuric chloride. Jour. Mar. Biol. Assoc. U.K. 54: 157.

Davies, A.G. 1976. An assessment of the basis of mercury tolerance in Dunaliella tertiolecta. Jour. Mar. Biol. Assoc. U.K. 56: 39.

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.

DeCoursey, P.J. and W.B. Vernberg. 1972. Effect of mercury on survival, metabolism and behavior of larval Uca pugilator (Brachyura). Oikos 23: 241.

De Filippis, L.F. 1979. The effect of sub-lethal concentrations of mercury and zinc on Chlorella. V. The concentration of metal toxicity by selenium and sulphhydryl compounds. Z. Pfhanzenphysiol. 93: 63.

de Freitas, A.S.W. and J.S. Hart. 1975. Effect of body weight on uptake of methyl mercury by fish. In: S. Barabas (ed.), Water Quality Parameters. ASTM STP 573. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 356.

de Freitas, A.S.W., et al. 1974. Origins and fate of mercury compounds in fish. In: Proceedings of the International Conference on Transport of Persistent Chemicals in Aquatic Ecosystems. Part III. National Research Council of Canada, Ottawa. p. 31.

de Freitas, A.S.W., et al. 1977. Factors affecting whole-body retention of methyl mercury in fish. In: Biological Implications of Heavy Metals in the Environment. p. 441.

de Freitas, A.S.W., et al. 1981. Mercury bioaccumulation in the detritus-feeding benthic invertebrate, _Hyalella azteca_ (Saussure). Proc. N.S. Inst. Sci. 31: 217.

Deshmukh, S.S. and V.B. Marathe. 1980. Size related toxicity of copper and mercury to _Lebistes reticulatus_ (Peter), _Labeo rohita_ (Ham.) and _Cyprinus carpio_ (Linn.). Indian Jour. Exp. Biol. 18: 421.

Dial, N.A. 1976. Methylmercury: teratogenic and lethal effects in frog embryos. Teratology 13: 327.

Dial, N.A. 1978a. Methylmercury: some effects on embryogenesis in the Japanese medaka, _Oryzias latipes_. Teratology 17: 83.

Dial, N.A. 1978b. Some effects of methylmercury on development of the eye in medaka fish. Growth 42: 309.

Dillon, T.M. 1977. Mercury and the estuarine marsh clam, _Rangia cuneata_ Gray. I. toxicity. Arch. Environ. Contam. Toxicol. 6: 249.

Dillon, T.M. and J.M. Neff. 1978. Mercury and the estuarine marsh clam, _Rangia cuneata_ Gray. II. uptake, tissue distribution and depuration. Mar. Environ. Res. 1: 67.

DiNardi, S.R., et al. 1974. Mercury concentrations in tissues of fish from the Connecticut River. Jour. Environ. Health 36: 547.

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

Dorn, P. 1976. The feeding behaviour of *Mytilus edulis* in the presence of methylmercury acetate. Bull. Environ. Contam. Toxicol. 15: 174.

Doyle, M., et al. 1976. Acute toxicological response of the crayfish (*Orconectes limosus*) to mercury. Bull. Environ. Contam. Toxicol. 16: 422.

Drummond, R.A., et al. 1974. Cough response and uptake of mercury by brook trout, *Salvelinus fontinalis*, exposed to mercuric compounds at different hydrogen-ion concentrations. Trans. Am. Fish. Soc. 103: 244.

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

Eisler, R. and R.J. 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. Acute toxicology of sodium nitrolotriacetic acid (NTA) and NTA-containing detergents to marine organisms. Water Res. 6: 1009.

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.

Ellis, M.M. 1947. Toxicity of phenyl-mercuric lactate for fish. Special Scientific Report No. 42. U.S. Fish and Wildlife Service.

Feick, G., et al. 1972. Release of mercury from contaminated freshwater sediments by the runoff of road deicing salts. Science 175: 1142.

Finley, M.T. and R.C. Stendell. 1978. Survival and reproductive success of black ducks fed methyl mercury. Environ. Pollut. 16: 51.

Flegal, A.R., et al. 1981. Elevated concentrations of mercury in mussels (*Mytilus californianus*) associated with pinniped colonies. Mar. Biol. 65: 45.

Fromm, P.O. 1977. Toxic effect of water soluble pollutants on freshwater fish. EPA-600/3-77-057. National Technical Information Service, Springfield, Virginia.

Fromm, P.O. 1980. A review of some physiological and toxicological responses of freshwater fish to acid stress. Environ. Biol. Fish. 5: 79.

Fujita, M. and K. Hashizume. 1972. The accumulation of mercury by freshwater planktonic diatom. Chemosphere 5: 203.

Gage, J.C. 1964. Distribution and excretion of methyl and phenyl mercury salts. Br. Jour. Ind. Med. 21: 197.

Gancher, H.E. 1978. Modification of methylmercury toxicity and metabolism by selenium and vitamin E: possible mechanisms. Environ. Health Perspect. 25: 71.

Gancher, H.E. 1980. Interactions of vitamin E and selenium with mercury and silver. Ann. New York Acad. Sci. 355: 212.

Gardner, G.R. 1975. Chemically induced lesions in estuarine or marine teleosts. In: *W.E. Ribelin and G. Migaki (eds.), The Pathology of Fishes.* University of Wisconsin Press, Madison, Wisconsin. p. 657.

Gast, C.H. and J.C. Kraak. 1979. Phase systems and post-column dithizone reaction detection for the analysis of mercurials by HPLC. Int. Jour. Environ. Anal. Chem. 6: 297.

Gentile, J.H., et al. 1982. The use of life-tables for evaluating the chronic toxicity of pollutants to Mysidopsis bahia. Hydrobiologia 93: 179.

Gentile, J.H., et al. 1983. The effects of a chronic mercury exposure on survival, reproduction and population dynamics of Mysidopsis bahia. Environ. Toxicol. Chem. 2: 61.

Giblin, F.J. and E.J. Massaro. 1973. Pharmacodynamics of methyl mercury in the rainbow trout (Salmo gairdneri): tissue uptake, distribution and excretion. Toxicol. Appl. Pharmacol. 24: 81.

Gipps, J.F. and P. Biro. 1978. The use of Chlorella vulgaris in a simple demonstration of heavy metal toxicity. Jour. Biol. Educ. 12: 207.

Glickstein, N. 1978. Acute toxicity of mercury and selenium to Crassostrea gigas embryos and Cancer magister larvae. Mar. Biol. 49: 113.

Glooschenko, W.A. 1969. Accumulation of ^{203}Hg by the marine diatom Chaetoceros costatum. Jour. Phycol. 5: 224.

Gray, J.S. and R.J. Ventilla. 1973. Growth rates of sediment-living marine protozoan as a toxicity indicator for heavy metals. Ambio 2: 118.

Green, F.A., Jr., et al. 1976. Effect of mercury on the survival, respiration and growth of postlarval white shrimp, Penaeus setiferus. Mar. Biol. 37: 75.

Gutierrez-Galindo, E.A. 1981. Effet de l'EDTA sur l'accumulation et l'elimination du mercure par la moule Mytilus edulis. Chemosphere 10: 971.

Hahne, H.C.H. and W. Kroontje. 1973. Significance of pH and chloride concentration on behavior of heavy metal pollutants: mercury(II), cadmium(II), zinc(II), and lead(II). Jour. Environ. Qual. 2: 444.

Haines, T.A. 1981. Acidic precipitation and its consequences for aquatic ecosystems. Trans. Am. Fish. Soc. 110: 669.

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

Hamdy, M.K. 1977. Biochemical transformation and detoxification of mercury in aquatic environment. PB 267926. National Technical Information Service, Springfield, Virginia.

Hamdy, M.K. and N.V. Prabhu. 1979. Behavior of mercury in biosystems III. biotransference of mercury through food chains. Bull. Environ. Contam. Toxicol. 21: 170.

Hamelink, J.L., et al. 1977. Mechanisms of bioaccumulation of mercury and chlorinated hydrocarbon pesticides by fish in lentic ecosystems. In: I.H. Suffet (ed.), Fate of Pollutants in the Air and Water Environments. Part II. Chemical and Biological Fate of Chemicals in the Environment. Wiley, New York. p. 261.

Hannan, P.J. and C. Patouillet. 1972. Effect of mercury on algal rates. Biotechnol. Bioeng. 14: 93.

Hannan, P.J., et al. 1973a. ^{203}Hg as tracer on pigments of Phaeodactylum tricornutum. Int. Jour. Appl. Radiat. Isotopes 24: 665.

Hannan, P.J., et al. 1973b. Measurements of mercury sorption by algae. Report 7628: 1. U.S. Naval Research Laboratory, Washington, D.C.

Hannerz, L. 1968. Experimental investigations on the accumulation of mercury in water organisms. Report No. 48. Institute of Freshwater Research, Drottningholm, Sweden. p. 120.

Hansen, D.J. 1983. Memorandum to William A. Brungs on results of acute toxicity tests with metals. U.S. EPA, Narragansett, Rhode Island.

Hara, T.J., et al. 1976. Effects of mercury and copper on the olfactory response in rainbow trout, Salmo gairdneri. Jour. Fish. Res. Board Can. 33: 1568.

Harriss, R.C., et al. 1970. Mercury compounds reduce photosynthesis by plankton. Science 170: 736.

Hartman, A.M. 1978. Mercury feeding schedules: effects on accumulation, retention, and behavior in trout. Trans. Am. Fish. Soc. 107: 369.

Hartung, R. 1976. Pharmacokinetic approaches to the evaluation of methylmercury in fish. In: R.W. Andrew, et al. (eds.), Toxicity to Biota of Metal Forms in Natural Water. International Joint Commission, Windsor, Ontario. p. 233.

Hattula, M.L., et al. 1978. Total mercury and methyl mercury contents in fish from Lake Paijanne. Environ. Pollut. 17: 19.

Havlik, B., et al. 1979. Mercury circulation in aquatic environment. Part 2: metabolism of methyl and phenyl mercury in phytoplankton. Acta Hydrochim. Hydrobiol. 7: 401.

Heinz, G.H. 1979a. Methylmercury: reproductive and behavioral effects on three generations of mallard ducks. Jour. Wildl. Manage. 43: 394.

Heinz, G. 1979b. Letter to H. McCormick. U.S. Fish and Wildlife Service, Laurel, Maryland. May 4.

Heinz, G.H., et al. 1980. Organochlorine and mercury residues in snakes from Pilot and Spider Islands, Lake Michigan - 1978. Bull. Environ. Contam. Toxicol. 25: 738.

Heisinger, J.F. 1981. Antagonism of selenium and cadmium pretreatments to subsequent embryotoxic doses of mercury and cadmium in fish embryos. PB82-256645. National Technical Information Service, Springfield, Virginia.

Heisinger, J.F. and W. Green. 1975. Mercuric chloride uptake by eggs of the ricefish and resulting teratogenic effects. Bull. Environ. Contam. Toxicol. 14: 665.

Heisinger, J.F., et al. 1979. Effect of selenium dioxide on the accumulation and acute toxicity of mercuric chloride in goldfish. Arch. Environ. Contam. Toxicol. 8: 279.

Heiskary, S.A. and D.D. Helwig. 1983. Acid rain intensive study lake program. Status report for the 1981 study lakes. Minnesota Pollution Control Agency, Roseville, Minnesota.

Heit, M. 1981. Letter to J.H. McCormick. U.S. EPA, Duluth, Minnesota. January 27.

Heit, M. and M. Fingerman. 1977. The influences of size, sex and temperature on the toxicity of mercury to two species of crayfishes. Bull. Environ. Contam. Toxicol. 18: 572.

Helwig, D.D. and M.E. Hora. 1983. Polychlorinated biphenyl, mercury, and cadmium concentrations in Minnesota snapping turtles. Bull. Environ. Contam. Toxicol. 30: 186.

Hendrick, R.D. and T.R. Everett. 1965. Toxicity to the Louisana red crawfish of some pesticides used in rice culture. Jour. Econ. Entomol. 58: 958.

Herrick, C.J., et al. 1982. A model of mercury contamination in a woodland stream. Ecol. Model. 15: 1.

Hildebrand, S.G., et al. 1980. Mercury accumulation in fish and invertebrates of the North Fork Holston River, Virginia and Tennessee. Jour. Environ. Qual. 9: 393.

Hilmy, A.M., et al. 1981. A comparative study of mercury poisoning on Aphanius dispar (Teleostei), Sergestes lucens (Crustacea) and Modiolus modiolus (Mollusca) of the Red Sea. Comp. Biochem. Physiol. 68C: 199.

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

Holderness, J., et al. 1975. The effect of methyl mercury on the growth of the green alga, Coelastrum microporum Naeg. strain 280. Bull. Environ. Contam. Toxicol. 13: 348.

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.

Hopkins, R. and J.M. Kain. 1971. The effect of marine pollutants on Laminarea hyperboria. Mar. Pollut. Bull. 2: 75.

Huckabee, J.W. 1972. Mercury concentrations in fish of the Great Smoky Mountains National Park. ORNL-TM-3908. National Technical Information Service, Springfield, Virginia.

Huckabee, J.W. and N.A. Griffith. 1974. Toxicity of mercury and selenium to the eggs of carp (Cyprinus carpio). Trans. Am. Fish. Soc. 103: 822.

Huckabee, J.W., et al. 1974. Mercury concentrations in fish from the Great Smoky Mountains National Park. Anal. Chimica Acta 70: 41.

Huckabee, J.W., et al. 1978. Methylated mercury in brook trout (*Salvelinus fontinalis*: absence of an *in vitro* methylating process. Trans. Am. Fish. Soc. 107: 848.

Huckabee, J.W., et al. 1979. Accumulation of mercury in freshwater biota. *In*: J.O. Nriagu (ed.), The Biogeochemistry of Mercury in the Environment. Elsevier, New York. p. 277.

Jackim, E. 1973. Influence of lead and other metals on fish delta-amino-levulinate dehydrase activity. Jour. Fish. Res. Board Can. 30: 560.

Jackim, E., et al. 1970. Effects of metal poisoning on five liver enzymes in the killifish (*Fundulus heteroclitus*). Jour. Fish. Res. Board Can. 27: 383.

Jarvenpaa, T., et al. 1970. Methylmercury: half-time of elimination in flounder, pike and eel. Suom. Kemistil. B43: 439.

Jensen, K., et al. 1981. Heavy metal pollution from a point source demonstrated by means of mussels, *Mytilus edulis*. Chemosphere 10: 761.

Jernelov, A. 1968. Laboratory experiments on the change of mercury compounds from one into another. Vatten 24: 360. (Translation Series No. 1352. 1970. Freshwater Institute, Winnipeg, Manitoba, Canada.)

Jernelov, A. 1971. Mercury - a case study of marine pollution. In: D. Dyrssen and D. Jagner (eds.), The Changing Chemistry of the Oceans. Wiley, New York. p. 161.

Jernelov, A. 1972. Factors in the transformation of mercury to methylmercury. In: R. Hartung and B.D. Dinman (eds.), Environmental Mercury Contamination. Ann Arbor Science Publishers, Ann Arbor, Michigan. p. 167.

Jernelov, A. 1980. The effects of acidity on the uptake of mercury in fish. Environ. Sci. Res. 17: 211.

Jernelov, A. and H. Lann. 1971. Mercury accumulation in food chains. Oikos 22: 403.

Jernelov, A., et al. 1975. Swedish perspectives on mercury pollution. Jour. Water Pollut. Control. Fed. 47: 810.

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

Jones, J.R.E. 1935. The toxic action of heavy metal salts on the three-spined stickleback (Gastrosteus aculeatus). Jour. Exp. Biol. 12: 165.

Jones, J.R.E. 1938. The relative toxicity of salts of lead, zinc and copper to the stickleback (<u>Gasterosteus aculeatus</u> L.) and the effect of calcium on the toxicity of lead and zinc salts. Jour. Exp. Biol. 15: 394.

Jones, J.R.E. 1939a. Antagonism between salts of the heavy and alkaline-earth metals in their toxic action on the tadpole of the toad, <u>Bufo bufo bufo</u> (L.). Jour. Exp. Biol. 16: 313.

Jones, J.R.E. 1939b. The relation between the electrolytic solution pressures of the metals and their toxicity to the stickleback (<u>Gasterosteus aculeatus</u> L.). Jour. Exp. Biol. 16: 425.

Jones, J.R.E. 1940. A further study of the relation between toxicity and solution pressure, with <u>Polycelis nigra</u> as test animal. Jour. Exp. Biol. 17: 408.

Jones, J.R.E. 1947. The oxygen consumption of <u>Gasterosteus aculeatus</u> L. in toxic solutions. Jour. Exp. Biol. 23: 298.

Jones, M.B. 1973. Influence of salinity and temperature on the toxicity of mercury to marine and brackish water isopods (Crustacea). Estuarine Coastal Mar. Sci. 1: 425.

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.

Joshi, A.G. and M.S. Rege. 1980. Acute toxicity of some pesticides and a few inorganic salts to the mosquito fish *Gambusia affinis* (Baird and Girard). Indian Jour. Exp. Biol. 18: 435.

Kayser, H. 1976. Waste-water assay with continous algal cultures: the effect of mercuric acetate on the growth of some marine dinoflagellates. Mar. Biol. 36: 61.

Khangarot, B.S., et al. 1982. Comparative toxicity of heavy metals and interaction of metals on a freshwater pulmonate snail *Lymnaea acuminata* (Lamarck). Acta Hydrochim. Hydrobiol. 10: 367.

Kihlstrom, J.E. and L. Hulth. 1972. The effect of phenylmercuric acetate upon the frequency of hatching of eggs from the zebrafish. Bull. Environ. Contam. Toxicol. 7: 111.

Kim, J.H., et al. 1977a. Protective action of selenium against mercury in northern creek chubs. Proc. South Dakota Acad. Sci. 55: 176.

Kim, J.H., et al. 1977b. Protective action of selenium against mercury in northern creek chubs. Bull. Environ. Contam. Toxicol. 17: 132.

Klaunig, J., et al. 1975. Acute toxicity of a native mummichog population (*Fundulus heteroclitus*) to mercury. Bull. Environ. Contam. Toxicol. 14: 534.

Klaverkamp, J.F., et al. 1983a. Joint toxicity of mercury and selenium on salmonid eggs. Arch. Environ. Contam. Toxicol. 12: 415.

Klaverkamp, J.F., et al. 1983b. Selenite toxicity and mercury-selenium interactions in juvenile fish. Arch. Environ. Contam. Toxicol. 12: 405.

Klaverkamp, J.F., et al. 1983c. Fates of metal radiotracers added to a whole lake: accumulation in slimy sculpin (*Cottus cognatus*) and white sucker (*Catostomus commersoni*). Sci. Total Environ. 28: 119.

Knowles, S.C. and R.G. Zingmark. 1978. Mercury and temperature interactions on the growth rates of three species of freshwater phytoplankton. Jour. Phycol. 14: 104.

Kopfler, F.C. 1974. The accumulation of organic and inorganic mercury compounds by the eastern oyster (*Crassostrea virginica*). Bull. Environ. Contam. Toxicol. 11: 275.

Krishnaja, A.P. and M.S. Rege. 1982. Induction of chromosomal aberrations in fish *Boleophthalmus dussumieri* after exposure in vivo to mitomycin C and heavy metals mercury, selenium and chromium. Mutat. Res. 102: 71.

Kucera, E. 1983. Mink and otter as indicators of mercury in Manitoba waters. Can. Jour. Zool. 61: 2250.

Kudo, A., et al. 1982. Proportion of methylmercury to the total amount of mercury in river waters in Canada and Japan. Water Res. 16: 1011.

Larson, D.W. 1976. Enhancement of methylmercury uptake in fish by lake temperature, pH, and dissolved oxygen gradients: hypothesis. Northwest Sci. 51: 131.

Laumond, F., et al. 1973. Experimental investigations, at laboratory, on the transfer of mercury in marine trophic chains. Rev. Int. Oceanogr. Med. 31-32: 47-53.

Lawrence, S.G. and M.H. Holoka. 1983. Effect of selenium on impounded zooplankton in a mercury contaminated lake. In: N.K. Kaushik and K.R. Solomon (eds.), Proceedings of the Eighth Annual Aquatic Toxicity Workshop. Can. Tech. Rept. Fish. Aquat. Sci. No. 1151. Dept. of Fisheries and Oceans, Ottawa, Ontario, Canada. p. 83.

Leonzio, C., et al. 1982. Complementary accumulation of selenium and mercury in fish muscle. Sci. Total Environ. 24: 249.

Lock, R.A.C. and A.P. van Overbeeke. 1981. Effects of mercuric chloride and methylmercuric chloride on mucus secretion in rainbow trout, Salmo gairdneri Richardson. Comp. Biochem. Physiol. 69C: 67.

Lock, R.A.C., et al. 1981. Effects of mercuric chloride and methylmercuric chloride on the osmoregulatory function of the gills in rainbow trout, Salmo gairdneri Richardson. Comp. Biochem. Physiol. 68C: 151.

Lockhart, W.L., et al. 1972. Methylmercury in northern pike (Esox lucius): distribution, elimination, and some biochemical characteristics of contaminated fish. Jour. Fish. Res. Board Can. 29: 1519.

Lockwood, A.P.M. and C.B.E. Inman. 1975. Diuresis in the amphipod, Gammarus duebeni, induced by methylmercury, D.D.T., lindane and fenithrothion. Comp. Biochem. Physiol. 52C: 75.

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.

Lucu, C. and M. Skreblin. 1981. Evidence on the interaction of mercury and selenium in the shrimp Palaemon elegans. Mar. Environ. Res. 5: 265.

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.

Luten, J.B., et al. 1980. Mercury and selenium in marine and freshwater fish. Jour. Food Sci. 45: 416.

MacCrehan, W.A. and R.A. Durst. 1978. Measurement of organomercury species in biological samples by liquid chromatography with differential pulse electrochemical detection. Anal. Chem. 50: 2108.

MacCrimmon, H.R., et al. 1983. Mercury uptake by lake trout, Salvelinus namaycush, relative to age, growth, and diet in Tadenac Lake with comparative data from other Precambrian Shield Lakes. Can. Jour. Fish. Aquat. Sci. 40: 114.

MacInnes, J.R. and A. Calabrese. 1978. Response of the embryos of the American oyster, Crassostrea virginica, to heavy metals at different temperatures. In: D.S. McLusky and A.J. Berry (eds.), Physiology and Behaviour of Marine Organisms. Pergamon Press, New York. p. 195.

MacLeod, J.C. and E. Pessah. 1973. Temperature effects on mercury accumulation, toxicity, and metabolic rate in rainbow trout (Salmo gairdneri). Jour. Fish. Res. Board Can. 30: 485.

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.

Martin, M., et al. 1981. Toxicity of ten metals to Crassostrea gigas and Mytilus edulis embryos and Cancer magister larvae. Mar. Pollut. Bull. 12: 305.

Martin, M., et al. 1984. Relationships between physiological stress and trace toxic substances in the bay mussel, *Mytilus edulis*, from San Francisco Bay, California. Mar. Environ. Res. 11: 91.

Mathur, S., et al. 1981. Acute toxicity of mercury, copper and zinc to a freshwater pulmonate snail, *Lymnaea luteola* (Lamarck). Acta Hydrochim. Hydrobiol. 9: 381.

Matida, Y., et al. 1971. Toxicity of mercury compounds to aquatic organisms and accumulation of the compounds by the organisms. Bull. Freshwater Fish. Res. Lab. 21: 197.

Matson, R.S., et al. 1972. Mercury inhibition of lipid biosynthesis in freshwater algae. Environ. Sci. Technol. 6: 158.

Matsumura, F., et al. 1975. Incorporation of ^{203}Hg into methylmercury in fish liver: studies on biochemical mechanisms *in vitro*. Environ. Res. 10: 224.

May, T.W. and G.L. McKinney. 1981. Cadmium, lead, mercury, arsenic, and selenium concentrations in freshwater fish, 1976-77 -- national pesticide monitoring program. Pestic. Monit. Jour. 15: 14.

McClurg, T.P. 1984. Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*. Water S A 10: 40.

McIntyre, J.D. 1973. Toxicity of methyl mercury for steelhead trout sperm. Bull. Environ. Contam. Toxicol. 9: 98.

McKim, J.M., et al. 1976. Long-term effects of methylmercuric chloride on three generations of brook trout (*Salvelinus fontinalis*): toxicity, accumulation, distribution, and elimination. Jour. Fish. Res. Board Can. 33: 2726.

McKone, C.E., et al. 1971. Rapid uptake of mercuric ion by goldfish. Environ Sci. Technol. 5: 1138.

Medeiros, D.M., et al. 1980. A possible physiological uptake mechanism of methylmercury by the marine bloodworm (*Glycera dibranchiata*). Bull. Environ. Contam. Toxicol. 24: 97.

Mellinger, P.J. 1973. The comparative metabolism of two mercury compounds as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*. *In*: D.D. Hemphill (ed.), Trace Substances in Environmental Health-VI. University of Missouri, Columbia, Missouri. p. 173.

Menezes, M.R. and S.Z. Qasim. 1983. Determination of acute toxicity levels of mercury to the fish *Tilapia mossambica* (Peters). Proc. Indian Acad. Sci. (Animal Sci.) 92: 375.

Middaugh, D.P. and C.L. Rose. 1974. Retention of two mercuricals by striped mullet, *Mugil cephalus*. Water Res. 8: 173.

Miller, D.R. and H. Akagi. 1979. pH affects mercury distribution, not methylation. Ecotoxicol. Environ. Safety 3: 36.

Miller, D.S. 1980. $HgCl_2$ inhibition of nutrient transport in teleost fish small intestine. Jour. Pharmacol. Exp. Ther. 216: 70.

Miller, D.S. 1981. Heavy metal inhibition of p-aminohippurate transport in flounder renal tissue: sites of $HgCl_2$ action. Jour. Pharmacol. Exp. Ther. 219: 428.

Mills, A.L. and R.R. Colwell. 1977. Microbiological effects of metal ions in Chesapeake Bay water and sediment. Biol. Environ. Contam. Toxicol. 18: 99.

Ming-Shan, H. and P.L. Zubkoff. 1982. The effects of mercury, copper, and zinc on calcium uptake by larvae of the clam, *Mulinia lateralis*. Water Air Soil Pollut. 17: 409.

Mitchell, J.W., et al. 1982. Mercury in takeaway fish in New Zealand. New Zealand Med. Jour. 95: 112.

Mora, B. and J. Fabregas. 1980. The effect of inorganic and organic mercury on growth kinetics of *Nitzchia acicularis* W. Sm. and *Tetraselmis suecica* Butch. Can. Jour. Microbiol. 26: 930.

Moore, J.W. and D.J. Sutherland. 1980. Mercury concentrations in fish inhabiting two polluted lakes in northern Canada. Water Res. 14: 903.

Morgan, W.S.G. 1979. Fish locomotor behavior patterns as a monitoring tool. Jour. Water Pollut. Control Fed. 51: 580.

Murray, A.R. 1978. An analysis of mercury contamination of fish from northern Saskatchewan Lakes, 1969-76. Technical Report No. 2. Department of Northern Saskatchewan Fisheries.

Murti, R. and G.S. Shuka. 1984. Acute toxicity of mercuric chloride and cadmium chloride to freshwater prawn, Macrobrachium lamarrei (H. Milne Edwards). Acta Hydrochim. Hydrobiol. 12: 689.

Mysing-Gubala, M. and M.A. Poirrier. 1981. The effects of cadmium and mercury on gemmule formation and gemmosclere morphology in Ephydatia fluviatilis (Porifera: Spongillidae). Hydrobiologia 76: 145.

Nagashima, J., et al. 1983. Accumulation of mercury by tissues in the short-necked clam Tapes japonica. Bull. Jap. Soc. Sci. Fish. 49: 801.

National Research Council. 1978. An assessment of mercury in the environment. National Academy of Sciences, Washington, D.C.

National Research Council of Canada. 1979. Effects of mercury in the Canadian environment. NRCC No. 16739. Ottawa, Ontario, Canada.

Nelson, D.A., et al. 1976. Biological effects of heavy metals on juvenile bay scallops, *Argopecten irradians*, in short-term exposures. Bull. Environ. Contam. Toxicol. 16: 275.

Niimi, A.J. and L. Lowe-Jinde. 1984. Differential blood cell ratios of rainbow trout (*Salmo gairdneri*) exposed to methylmercury and chlorobenzenes. Arch. Environ. Contam. Toxicol. 13: 303.

Norstrom, R.J., et al. 1976. A bioenergetics-based model for pollutant accumulation by fish. Simulation of PCB and methylmercury residue levels in Ottawa River yellow perch (*Perca flavescens*). Jour. Fish. Res. Board Can. 33: 248.

Nriagu, J.O. (ed.). 1979. The Biogeochemistry of Mercury in the Environment. Elsevier, New York.

Nuzzi, R. 1972. Toxicity of mercury to phytoplankton. Nature 237: 38.

Okubo, K. and T. Okubo. 1962. Study on the bioassay method for the evaluation of water pollution - II. use of the fertilized eggs of sea urchins and bivalves. Bull. Tokai Reg. Fish. Res. Lab. 32: 131.

Olson, G.F., et al. 1975. Mercury residues in fathead minnows, *Pimephales promelas* Rafinesque, chronically exposed to methylmercury in water. Bull. Environ. Contam. Toxicol. 14: 129.

Olson, K.R. and R.C. Harrel. 1973. Effect of salinity on acute toxicity of mercury, copper, and chromium for Rangia cuneata (Pelecypoda, Mactridae). Contrib. Mar. Sci. 17: 9.

Olson, K.R., et al. 1978. Tissue uptake, subcellular distribution, and metabolism of $^{14}CH_3HgCl$ and $CH_3{}^{202}HgCl$ by rainbow trout, Salmo gairdneri. Jour. Fish. Res. Board Can. 35: 381.

Overnell, J. 1975. The effect of heavy metals on photosynthesis and loss of cell potassium in two species of marine algae, Dunaliella tertiolecta and Phaeodactylum tricornutum. Mar. Biol. 29: 99.

Paasivirta, J., et al. 1981. Recent trends of biocides in pikes of the Lake Paijanne. Chemosphere 10: 405.

Paasivirta, J., et al. 1983. Food chain enrichment of organochlorine compounds and mercury in clean and polluted lakes of Finland. Chemosphere 12: 239.

Panigrahi, A.K. and B.N. Misra. 1980. Toxicological effects of a sub-lethal concentration of inorganic mercury on the fresh water fish, Tilapia mossambica, Peters. Arch. Toxicol. 44: 269.

Parker, J.G. 1984. The effects of selected chemicals and water quality on the marine polychaete Ophryotrocha diadema. Water Res. 18: 865.

Parrish, K.M. and R.A. Carr. 1976. Transport of mercury through a laboratory two-level marine food chain. Mar. Pollut. Bull. 7: 90.

Passino, D.R.M. and C.A. Cotant. 1979. Allantoinase in lake trout (*Salvelinus namaycush*): in vitro effects of PCBs, DDT and metals. Comp. Biochem. Physiol. 62C: 71.

Pennacchioni, A., et al. 1976. Inability of fish to methylate mercuric chloride in vivo. Jour. Environ. Qual. 5: 451.

Pennington, C.H., et al. 1982. Contaminant levels in fishes from Brown's Lake, Mississippi. Jour. Mississippi Acad. Sci. 27: 139.

Persoone, G. and G. Uyttersprot. 1975. The influence of inorganic and organic pollutants on the rate of reproduction of a marine hypotrichous ciliate: *Euplotes vannus* Muller. Rev. Int. Oceanogr. Med. 37-38: 125.

Phillips, G.R. and D.R. Buhler. 1978. The relative contributions of methylmercury from food or water to rainbow trout (*Salmo gairdneri*) in a controlled laboratory environment. Trans. Am. Fish. Soc. 107: 853.

Phillips, G.R. and D.R. Buhler. 1980. Mercury accumulation in and growth rate of rainbow trout, *Salmo gairdneri*, stocked in an eastern Oregon reservoir. Arch. Environ. Contam. Toxicol. 9: 99.

Phillips, G.R. and R.W. Gregory. 1979. Assimilation efficiency of dietary methylmercury by northern pike (*Esox lucius*). Jour. Fish. Res. Board Can. 36: 1516.

Phillips, G.R. and R.W. Gregory. 1980. Accumulation of selected elements (As, Cu, Hg, Pb, Se, Zn) by northern pike (*Esox lucius*) reared in surface coal mine decant water. Proc. Montana Acad. Sci. 39: 44.

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.

Phillips, G.R., et al. 1980. Relation between trophic position and mercury accumulation among fishes from the Tongue River Reservoir, Montana. Environ. Res. 22: 73.

Portmann, J.E. 1968. Progress report on a programme of insecticide analysis and toxicity-testing in relation to the marine environment. Helgol. Wiss. Meeresunters. 17: 247.

Price, R.E. and L.A. Knight, Jr. 1978. Mercury, cadmium, lead, and arsenic in sediments, plankton, and clams from Lake Washington and Sardis Reservoir, Mississippi, October 1975 - May 1976. Pestic. Monit. Jour. 11: 182.

Pyefinch, K.A. and J.C. Mott. 1948. The sensitivity of barnacles and their larvae to copper and mercury. Jour. Exp. Biol. 25: 296.

Qureshi, S.A. and A.B. Saksena. 1980. The acute toxicity of some heavy metals to Tilapia mossambica (Peters). Aqua 1: 19.

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.

Rai, L.C. 1979. Mercuric chloride effect on Chlorella. Phykos 18: 105.

Rai, L.C., et al. 1981. Protective effects of certain environmental factors on the toxicity of zinc, mercury, and methylmercury to Chlorella vulgaris. Environ. Res. 25: 250.

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.

Ramamoorthy, S., et al. 1982. Effect of microbial life stages on the fate of methylmercury in natural waters. Bull. Environ. Contam. Toxicol. 29: 167.

Ray, S., et al. 1984. Mercury and polychlorinated biphenyls in striped bass (Morone saxatilis) from two Nova Scotia rivers. Water Air Soil Pollut. 21: 15.

Reeve, M.R., et al. 1977. Evaluation of potential indicators of sub-lethal toxic stress on marine zooplankton (feeding, fecundity, respiration and excretion): controlled ecosystem pollution experiment. Bull. Mar. Sci. 27: 105.

Rehwoldt, R., et al. 1973. The acute toxicity of some heavy metal ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10: 291.

Reiichiro, H., et al. 1983. Accumulation of mercury by the marine copepod *Acartia clausi*. Bull. Jap. Soc. Sci. Fish. 49: 1249.

Reinert, R.E., et al. 1974. Effect of temperature on accumulation of methylmercuric chloride and p,p'DDT by rainbow trout (*Salmo gairdneri*). Jour. Fish. Res. Board Can. 31: 1649.

Reish, D.J. and R.S. Carr. 1978. The effect of heavy metals on the survival, reproduction, development, and life cycles for two species of polychaetous annelids. Mar. Pollut. Bull. 9: 24.

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.

Renfro, J.L., et al. 1974. Methylmercury and inorganic mercury: uptake, distribution, and effect on osmoregulatory mechanisms in fishes. In: F.J. Vernberg and W.B. Vernberg (eds.), Pollution and Physiology of Marine Organisms. Academic Press, New York p. 101.

Ribeyre, F. and A. Boudou. 1982. Study of the dynamics of the accumulation of two mercury compounds - $HgCl_2$ and CH_3HgCl - by *Chlorella vulgaris*: effect of temperature and pH factor of the environment. Int. Jour. Environ. Studies 20: 35.

Ribeyre, F., et al. 1980. Transfer of methylmercury in an experimental freshwater trophic chain - temperature effects. Environ. Pollut. (Series B) 1: 259.

Rodgers, D.W. and F.W.H. Beamish. 1981. Uptake of waterborne methylmercury by rainbow trout (Salmo gairdneri) in relation to oxygen consumption and methylmercury concentration. Can. Jour. Fish. Aquat. Sci. 38: 1309.

Rodgers, D.W. and F.W.H. Beamish. 1982. Dynamics of dietary methylmercury in rainbow trout, Salmo gairdneri. Aquat. Toxicol. 2: 271.

Rodgers, D.W. and F.W.H. Beamish. 1983. Water quality modifies uptake of waterborne methylmercury by rainbow trout, Salmo gairdneri. Can. Jour. Fish. Aquat. Sci. 40: 824.

Rodgers, D.W. and S.U. Qadri. 1982. Growth and mercury accumulation in yearling yellow perch, Perca flavescens, in the Ottawa River, Ontario. Environ. Biol. Fish. 7: 377.

Rodgers, E.O., et al. 1951. The toxicity of pyridylmercuric acetate technical (PMA) to rainbow trout (Salmo gairdnerii). Prog. Fish-Cult. 13: 71.

Rosko, J.J. and J.W. Rachlin. 1977. The effect of cadmium, copper, mercury, zinc and lead on cell division, growth, and chlorophyll _a_ content of the chlorophyte _Chlorella vulgaris_. Bull. Torrey Bot. Club 104: 226.

Rucker, R.R. 1948. New compounds for the control of bacterial gill disease. Prog. Fish-Cult. 10: 19.

Rucker, R.R. and W.J. Whipple. 1951. Effect of bactericides on steelhead trout fry. Prog. Fish-Cult. 13: 43.

Rudd, J.W.M. and M.A. Turner. 1983a. The English-Wabigoon River System: II. suppression of mercury and selenium bioaccumulation by suspended and bottom sediments. Can. Jour. Fish. Aquat. Sci. 40: 2218.

Rudd, J.W.M. and M.A. Turner. 1983b. The English-Wabigoon River System: V. mercury and selenium bioaccumulation as a function of aquatic primary productivity. Can. Jour. Fish. Aquat. Sci. 40: 2251.

Rudd, J.W.M., et al. 1980a. Dynamics of selenium in mercury-contaminated experimental freshwater ecosystems. Can. Jour. Fish. Aquat. Sci. 37: 848.

Rudd, J.W.M., et al. 1980b. Mercury methylation by fish intestinal contents. Appl. Environ. Microbiol. 40: 777.

Ruohtula, M. and J.K. Miettinen. 1975. Retention and excretion of ^{203}Hg-labelled methylmercury in rainbow trout. Oikos 26: 385.

Saxena, O.P. and A. Parashari. 1983. Comparative study of the toxicity of six heavy metals to *Channa punctatus*. Jour. Environ. Biol. 4: 91.

Scheider, W.A., et al. 1979. Effects of acidic precipitation on precambrian freshwaters in southern Ontario. Jour. Great Lakes Res. 5: 45.

Schmidt-Nielsen, B., et al. 1977. Effect of methylmercury upon osmoregulation, cellular volume, and ion regulation in winter flounder, *Pseudopleuronectes americanus*. *In*: F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 105.

Servizi, J.A. and D.W. Martens. 1978. Effects of selected heavy metals on early life of sockeye and pink salmon. Progress Report No. 39. International Pacific Salmon Fisheries Commission, New Westminister, B.C., Canada.

Shaffi, S.A. 1981. Mercury toxicity: biochemical and physiological alterations in nine freshwater teleosts. Toxicol. Letters 8: 187.

Sharma, D.C. and P.S. Davis. 1980a. Behavior of some radioactive compounds of mercury and selenium in aquarium water and their direct uptake by the goldfish *Carassius auratus*. Indian Jour. Exp. Biol. 18: 69.

Sharma, D.C. and P.S. Davis. 1980b. Effect of methylmercury on protein synthesis in liver of the European carp *Cyprinus carpio*. Indian Jour. Exp. Biol. 18: 1054.

Sharma, D.C. and P.S. Davis. 1980c. Effect of sodium selenite and seleno-methionine on the accumulation and acute toxicity of mercuric and methylmercuric chloride in the goldfish *Carassius auratus*. Indian Jour. Exp. Biol. 18: 82.

Sharma, D.C., et al. 1982. Effect of ascorbic acid on biotransformation and modification of the toxicity of mercurials in goldfish (*Carassius auratus*). Experientia 38: 565.

Sharp, J.R. and J.M. Neff. 1980. Effects of the duration of exposure to mercuric chloride on the embryogenesis of the estuarine teleost, *Fundulus heteroclitus*. Mar. Environ. Res. 3: 195.

Sharp, J.R. and J.M. Neff. 1982. The toxicity of mercuric chloride and methylmercuric chloride to *Fundulus heteroclitus* embryos in relation to exposure conditions. Environ. Biol. Fish. 7: 277.

Sharpe, M.A., et al. 1977. The effect of body size on methylmercury clearance by goldfish (*Carassius auratus*). Environ. Biol. Fish. 2: 177.

Shealy, M.H. and P.A. Sandifer. 1975. Effects of mercury on survival and development of the larval grass shrimp, *Palaemonetes vulgaris*. Mar. Biol. 33: 7.

Sheffy, T.B. 1978. Mercury burdens in crayfish from the Wisconsin River. Environ. Polluc. 17: 219.

Sheline, J. and B. Schmidt-Nielsen. 1977. Methylmercury-selenium: interaction in the killifish, Fundulus heteroclitus. In: F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 119.

Sick, L.V. and H.L. Windom. 1975. Effects of environmental levels of mercury and cadmium on rates of metal uptake and growth physiology of selected genera of marine phytoplankton. In: Mineral Cycling in Southeastern Ecosystems. CONF-740513. National Technical Information Service, Springfield, Virginia.

Sigmon, C.F., et al. 1977. Reductions in biomass and diversity resulting from exposure to mercury in artificial streams. Jour. Fish. Res. Board Can. 34: 493.

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 axolotl (Ambystoma mexicanum) and the clawed toad (Xenopus laevis) in the toxicological bioassays. Bull. Environ. Contam. Toxicol. 24: 439.

Slooff, W., et al. 1983. Comparison of the susceptibility of 22 freshwater species to 15 chemical compounds. I. (sub)acute toxicity tests. Aquat. Toxicol. 4: 113.

Snarski, V.M. and G.F. Olson. 1982. Chronic toxicity and bioaccumulation of mercuric chloride in the fathead minnow (*Pimephales promelas*). Aquat. Toxicol. 2: 143.

Sonntag, N.C. and W. Greve. 1977. Investigation of the impact of mercury on enclosed water columns using a zooplankton simulation mode. Jour. Fish. Res. Board Can. 34: 2295.

Sosnowski, S.L. and J.H. Gentile. 1978. Toxicological comparison of natural and cultured populations of *Acartia tonsa* to cadmium, copper, and mercury. Jour. Fish. Res. Board Can. 35: 1366.

Speyer, M.R. 1980. Mercury and selenium concentrations in fish, sediments, and water of two northwestern Quebec lakes. Bull. Environ. Contam. Toxicol. 24: 427.

Srivastava, D.K. 1982. Comparative effects of copper, cadmium and mercury on tissue glycogen of the catfish, *Heteropneustes fossilis* (Bloch). Toxicol. Letters 11: 135.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (*Myriophyllum spicatum* L.). Arch. Environ. Contam. Toxicol. 2: 331.

Stary, J. and K. Kratzer. 1980. Theory of the cumulation of mercury species in fish. Radiochem. Radioanal. Letters 44: 37.

Stary, J. and K. Kratzer. 1982. The cumulation of toxic metals on alga. Int. Jour. Environ. Anal. Chem. 12: 65.

Stary, J., et al. 1980. The cumulation of methylmercury in fish (*Poecilia reticulata*). Int. Jour. Environ. Anal. Chem. 8: 189.

Stary, J., et al. 1981. Mercury circulation in aquatic environment. Part 4: the cumulation of inorganic mercury and phenylmercury by fish (*Poecilia reticulata* (Peters)). Acta Hydrochim. Hydrobiol. 9: 545.

Stary, J., et al. 1982. The cumulation of methylmercury and phenylmercury species on alga. Jour. Indian. Chem. Soc. 59: 1329.

Stary, J., et al. 1983. Cumulation of zinc, cadmium, and mercury on the alga *Scenedesmus obliquus*. Acta Hydrochim. Hydrobiol. 11: 401.

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.

Stokes, P.M., et al. 1983. Mercury accumulation by filamentous algae: a promising biological monitoring system for methyl mercury in acid-stressed lakes. Environ. Pollut. (Series B) 5: 255.

Stopford, W. and L.J. Goldwater. 1975. Methylmercury in the environment: a review of current understanding. Environ. Health Perspect. 12: 115.

Stratton, G.W. and C.T. Corke. 1979. The effect of mercuric, cadmium, and nickel ion combinations on a blue-green alga. Chemosphere 10: 731.

Stratton, G.W., et al. 1979. Effect of mercuric ion on the growth, photosynthesis, and nitrogenase activity of *Anabaena inaequalis*. Appl. Environ. Microbiol. 38: 537.

Strom, S., et al. 1979. Mercury toxicity to hemopoietic and tumor colony-forming cells and its reversal by selenium *in vitro*. Toxicol. Appl. Pharmacol. 49: 431.

Stromgren, T. 1980. The effect of lead, cadmium, and mercury on the increase in length of five intertidal fucales. Jour. Exp. Mar. Biol. Ecol. 43: 107.

Summers, A.O. and S. Silver. 1978. Microbial transformations of metals. Ann. Rev. Microbiol. 32: 637.

Thayer, J.S. and F.E. Brinckman. 1982. The biological methylation of metals and metalloids. *In*: F.G. Stone and R. West (eds.), Advances in Organometallic Chemistry, Vol. 20. Academic Press, New York. p. 313.

Thomas, D.L. and J.G. Montes. 1978. Spectrophotometrically assayed inhibitory effects of mercuric compounds on *Anabaena flos-aquae* and *Anacystis nidulans* (Cyanophyceae). Jour. Phycol. 14: 494.

Thomas, W.H., et al. 1977. Controlled ecosystem pollution experiment: effect of mercury on enclosed water columns. III. phytoplankton population dynamics and production. Mar. Soc. Commun. 3: 331.

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.

Thurberg, P.P., et al. 1977. Response of the lobster, Homarus americanus, to sublethal levels of cadmium and mercury. In: F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 185.

Trevors, J.T. 1982. A comparison of methods for assessing toxicant effects on algal growth. Biotechnol. Letters 4: 243.

Tsai, S., et al. 1975. Importance of water pH in accumulation of inorganic mercury in fish. Bull. Environ. Contam. Toxicol. 13: 188.

Tsui, P.T.P. and P.J. McCart. 1981. Chlorinated hydrocarbon residues and heavy metals in several fish species from the Cold Lake Area in Alberta, Canada. Int. Jour. Environ. Anal. Chem. 10: 277.

Turner, M.A. and A.L. Swick. 1983. The English-Wabigoon River System: IV. interaction between mercury and selenium accumulated from waterborne and dietary sources by northern pike (Esox lucius). Can. Jour. Fish. Aquat. Sci. 40: 2241.

Ukeles, R. 1962. Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl. Microbiol. 10: 532.

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 mercury. EPA-440/5-80-058. 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. Technical support document for water quality-based toxics control. Office of Water, Washington, D.C.

U.S. Food and Drug Administration. 1984a. Guide 7108.07. Compliance Policy Guide. Compliance Guidelines Branch, Washington, D.C. November 6.

U.S. Food and Drug Administration. 1984b. Action level for methyl mercury in fish. Federal Register 49: 45663. November 19.

van den Broek, W.L.F. and D.M. Tracey. 1981. Concentration and distribution of mercury in flesh of orange roughy (*Hoplostethus atlanticus*). New Zealand Jour. Mar. Freshwater Res. 15: 255.

Verma, S.R., et al. 1984. Mercuric chloride stress on serum transaminase activity in *Notopterus notopterus*. Toxicol. Letters 20: 49.

Vernberg, W.B. and J. O'Hara. 1972. Temperature-salinity stress and mercury uptake in the fiddler crab, *Uca pugilator*. Jour. Fish. Res. Board Can. 29: 1491.

Vernberg, W.B. and J. Vernberg. 1972. The synergistic effects of temperature, salinity, and mercury on survival and metabolism of the adult fiddler crab, *Uca pugilator*. Fish. Bull. 70: 415.

Wachs, B. 1982. Concentration of heavy metals in fishes from the River Danube. Z. Wasser Abwasser Forsch. 15: 43.

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.

Waterman, A.J. 1937. Effect of salts of heavy metals on development of the sea urchin, *Arbacia punctulata*. Biol. Bull. 73: 401.

Watling, R.J., et al. 1981. Relation between mercury concentration and size in the Mako shark. Bull. Environ. Contam. Toxicol. 26: 352.

Weber, W.J., Jr., and W. Stumm. 1963. Mechanism of hydrogen ion buffering in natural waters. Jour. Am. Water Works Assoc. 55: 1553.

Weis, J.S. 1976. Effects of mercury, cadmium, and lead salts on regeneration and ecdysis in the fiddler crab, Uca pugilator. Fish. Bull. 74: 464.

Weis, J.S. 1977. Limb regeneration in fiddler crabs: species differences and effects of methylmercury. Biol. Bull. 152: 263.

Weis, J.S. and P. Weis. 1984. A rapid change in methylmercury tolerance in a population of killifish, Fundulus heteroclitus, from a golf course pond. Mar. Environ. Res. 13: 231.

Weis, J.S., et al. 1981. Methylmercury tolerance of killifish (Fundulus heteroclitus) embryos from a polluted vs non-polluted environment. Mar. Biol. 65: 283.

Weis, P. and J.S. Weis. 1977. Effects of heavy metals on development of the killifish, Fundulus heteroclitus. Jour. Fish Biol. 11: 49.

Weis, P. and J.S. Weis. 1978. Methylmercury inhibition of fin regeneration in fishes and its interaction with salinity and cadmium. Estuarine Coastal Mar. Sci. 6: 327.

Weis, P. and J.S. Weis. 1983. Effects of embryonic pre-exposure to methylmercury and Hg^{2+} on larval tolerance in *Fundulus heteroclitus*. Bull. Environ. Contam. Toxicol. 31: 530.

Weisbart, M. 1973. The distribution and tissue retention of mercury-203 in the goldfish (*Carassius auratus*). Can. Jour. Zool. 51: 143.

Westerman, A.G. and W.J. Birge. 1978. Accelerated rate of albinism in channel catfish exposed to metals. Prog. Fish-Cult. 40: 143.

Willford, W.A. 1966. Toxicity of 22 therapeutic compounds to six fishes. Investigations in fish control: 18. U.S. Fish and Wildlife Service, Washington, D.C.

Wobeser, G.A. 1973. Aquatic mercury pollution. Studies of its occurrence and pathologic effects on fish and mink. Ph.D. Thesis. University of Saskatchewan, Canada.

Wobeser, G., et al. 1976a. Mercury and mink. I. the use of mercury contaminated fish as a food for ranch mink. Can. Jour. Comp. Med. 40: 30.

Wobeser, G., et al. 1976b. Mercury and mink. II. experimental methyl mercury intoxication. Can. Jour. Comp. Med. 40: 34.

Wong, P.T.S., et al. 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11: 367.

Wood, J.M. 1974. Biological cycles for toxic elements in the environment. Science 183: 1049.

Wren, C.D. and H.R. MacCrimmon. 1983. Mercury levels in the sunfish, Lepomis gibbosus, relative to pH and other environmental variables of precambrian shield lakes. Can. Jour. Fish. Aquat. Sci. 40: 1737.

Wren, C.D., et al. 1983. Examination of bioaccumulation and biomagnification of metals in a precambrian shield lake. Water Air Soil Pollut. 19: 277.

Wright, D.R. and R.D. Hamilton. 1982. Release of methyl mercury from sediments: effects of mercury concentration, low temperature, and nutrient addition. Can. Jour. Fish. Aquat. Sci. 39: 1459.

Yamane, Y. and T. Koizumi. 1982. Protective effect of molybdenum on the acute toxicity of mercuric chloride. Toxicol. Appl. Pharmacol. 65: 214.

Young, L.G. and L. Nelson. 1974. The effects of heavy metal ions on the motility of sea urchin spematozoa. Biol. Bull. 147: 236.

Zubarik, L.S. and J.M. O'Connor. 1978. A radioisotopic study of mercury uptake by Hudson River biota. In: J.H. Thorp and J.W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Systems. CONF-771114. National Technical Information Service, Springfield, Virginia.