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# Ambient Water Quality Criteria for Ammonia (Saltwater)-1989

# AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR AMMONIA

# (SALT WATER)

U.S. ENVIRONMENTAL PROTECTION AGENCY
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## NOTICES

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.

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## 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 water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which might 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. Criteria contained in this document replace any previously published EPA aquatic life criteria for the same pollutants.

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. Criteria presented in this document are such scientific assess-merits. If water quality criteria associated with specific stream uses are adopted by a state as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentration in ambient waters within that state. Water quality criteria adopted in State water quality standards could have the same numerical values as the criteria developed under section 304. However, in many situations States might 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 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.

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## CONTENTS

Foreword. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .. .iii

Acknowledgements . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .. iv

Tables . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . vi

Introduction . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 1

Acute Toxicity to Saltwater Animals . . . . . . . . . . . . . . . . . . . . . . . . .7

Chronic Toxicity to Saltwater Animals. . . . . . . . . . . . . . . . . . . . . . . . 14

Toxicity to Aquatic Plants . . . . . . . . . . . . . . . . . . . . . . . . . 17

Other Data . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18

Unused Data . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 22

Summary . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 24

National Criteria . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

References . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48

## TABLES

1. Acute Toxicity Of Ammonia to Saltwater Animals. . . . . . . . . . . . . .32

2. Chronic Toxicity of Ammonia to Aquatic Animals . . . . . . . . . . . . . . . . .39

3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .43

4. Other Data on Effects of Ammonia on Saltwater Organism. . . . . . . 45

## INTRODUCTION*

in aqueous solutions, the ammonium ion dissociates to un-ionized ammonia and the hydrogen ion. The equilibrium equation can be written:

$$H_2O + NH^+ \rightleftharpoons NH_3 + H_3O^+ \quad (1)$$

The total ammonia concentration is the sum of $NH_3$ and $NH_4^+$.

The toxicity of aqueous ammonia solutions to aquatic organisms is primarily attributable to the un-ionized form, the ammonium ion being less toxic (Armstrong et al. 1978; Chipman 1934; Tabata 1962; Thurston et al. 1981; Wuhrmann et al. 1947; Wuhrmann and Woker 1948). It is necessary, therefore, to know the percentage of total ammonia which is in the un-ionized form in order to establish the corresponding total ammonia concentration toxic to aquatic life. The percentage of un-ionized ammonia (UIA) can be calculated from the solution pH and $pK_a^*$, the negative log of stoichiometric dissociation,

$$\% \text{ UIA} = 100 \, [\, 1 + 10^{((pK_a^* - pH)}]^{-1} \quad (2)$$

The stoichmetric dissociation constant is defined:

$$K_a^* \quad \frac{[NH_3] \; [H^+]}{[NH_4^+]} \quad (3)$$

where the brackets represent molal concentrations. $K_a^*$ is a function of the temperature and ionic strength of the solution.

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* 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, and the Response to public Comment (U.S. EPA 1985c), is necessary in order to understand the following text, tables, and calculations.

Whitfield (1974 developed theoretical models to determine the $pK_a^*$ of the ammonium ion in seawater. He combined his models with the infinite dilution data of Bates and Pinching (1949) to define general equations for the $pK_a^*$ of ammonium ion as a function of salinity and temperature.

Whitfield’s models allow reasonable approximations of the percent un-ionized ammonia in sea water and have been substantiated experimentally by Khoo et al. (1977). Hampson's (1977) program for Whitfield’s full seawater model has been used to calculate the un-ionized ammonia fraction of measured total ammonia concentrations in toxicity studies conducted by EPA and also in the derivation of most other acute and chronic ammonia values which contribute to the criteria. The equations for this model are:

$$\% \text{ UIA} = 100 \left[ 1 + 10 \left(X + 0.0324 (298-T) + 0.0415 \, P/T - pH\right)\right]^{-1} \quad (4)$$

where

P = 1 ATM for all toxicity testing reported to date;

T - temperature (°K);

X = $pK_a^s$ or the stoichiometric acid hydrolysis constant of ammonium ions in saline water based on I,

$$I = 19.9273 \, S \, (1000-1.005109 \, S)^{-1} \quad (5)$$

where

I = molal ionic strength of the sea water;

S = salinity (g/kg).

The Hampson program calculator the value for I for the test salinity (Eq. 5), finds the corresponding $pK_a^s$, then calculates % UIA (Eq. 4).

The major factors influencing the degree of ammonia dissociation are pH and temperature. Both correlate positively with un-ionized ammonia. Salinity, the least influential of the three water quality factors that control the fraction of un-ionized ammonia, is inversely correlated.

In ammonia toxicity testing, the pH is normally calibrated using low ionic strength National Bureau of Standards (NBS) buffers. In contrast, Khoo et al. (1977) used the free hydrogen ion sea water scale (ph(F)) in their measurements of ammonium ion hydrolysis in sea water. While the ph(F) scale is desirable from the thermodynamic standpoint, these seawater buffers are not available from a central source, precluding their use in toxicity testing. Calibration of pH with NBS buffers does contribute an error in the calculation of % un-ionized ammonia, although, fortuitously the error is small, presumably due to a compensation of the liquid junction potential by changes in activity coefficients (Bates and Culberson 1977). Millero (1986) found the pH(NBS) scale to overestimate pH relative to the free hydrogen ion scale by 0.02 pH unit at 30 g/kg salinity, 0.045 unit at 20 g/kg and 0.075 unit at 10 g/kg. The residual junction potential is a property of the reference electrode used and may vary $\pm$ 0.03 pH unit with salinity, time, and electrode type (Whitfield et al. 1985).

Controlling pH in salt water ammonia toxicity tests is difficult. Ammonium salt solutions are acidic, but are slow to reach equilibrium in sea water. Consequently, pH typically declines during toxicity tests and the decline may be amplified by metabolism of test organisms. Also, tests conducted above or below the seawater equilibrium pH (7.8-8.2) experience strong shifts toward the buffered state. Inconsistency in degree of control of test pH is a major source of variability in ammonia toxicity studies especially in sea water. A ± 0.1 pH unit variance would result in a misestimation of the $NH_3$ effect concentration of about ± 25% at pH 8 and 25°C.

A number of analytical methods are available for direct determination of total ammonia concentrations in aqueous solutions (Richards and Healey 1984). Once total ammonia is measured, and the pH, salinity and temperature of the solution dete[illegible] the concentration of $NH_3$ present can be calculated based on the ammonia-seawater equilibrium expression.

Ammonia concentrations have been reported in a variety of forms in the aquatic toxicity literature, such as $NH_3$, $NH_4^+$, $NH_3$-N, $NH_4OH$, $NH_4Cl$ and others. The use in the literature of the terms $NH_3$, $NH_3$-N, or ammonia-nitrogen may not necessarily mean un-ionized ammonia, but may be the author's way of expressing total ammonia. Compounds used in the ammonia toxicity tests summarized here are $NH_4Cl$, $NH_4NO_3$ and $(NH_4)_2SO_4$.

Throughout the remainder of this document, all quantitative ammonia data have been expressed in terms of mg/L un-ionized ammonia for ease in discussion and comparison, and since un-ionized ammonia is the principal toxic form. Ammonia concentrations reported by authors are given as reported if the author(s) provided data expressed as mg $NH_3$/L, or converted to mg/L if reported in other units. If authors reported only total ammonia, or if they calculated $NH_3$ concentration by a unique method (e.g., EA Eng. 1986), the total ammonia value and reported pH, temperature, and salinity conditions were used to calculate mg $NH_3$/L, per the Hampson (1977) program. This approach produces $NH_3$ values that are consistently derived.

Some literature cited in this document fail to provide $NH_3$ concentrations or total ammonia concentrations along with sufficient pH, temperature, and salinity data to enable calculation of $NH_3$ concentrations; such papers were not used but are cited under "Unused Data". In some instances information missing in published papers on experimental conditions was obtained through correspondence with authors; data obtained in this manner are so indicated by footnotes and are available from U.S. EPA, ERL, Narragansett.

A number of criteria documents, review articles and books dealing with ammonia as an aquatic pollutant are available. Armstrong (1979), Becker and Thatcher (1973), Colt and Armstrong (1981), Epler (1971), Hampson (1976), Liebmann (1960), McKee and Wolf (1963), Steffens (1976), and Tsai (1975) have published summaries of ammonia toxicity. Literature reviews, including factors affecting ammonia toxicity and physiological consequences of ammonia toxicity to aquatic organisms, have been published by Kinne (1976), Lloyd (1961), Lloyd and Herbert (1962), Lloyd and Swift (1976), Visek (1968), and Warren (1962). Literature reviews of ammonia toxicity information relating to criteria recommendations have been published by Alabaster and Lloyd (1980), European Inland Fisheries Advisory Commission (1970), National Academy of Sciences and National Academy of Engineering (1974), National Research Council (1979), U.S. Environmental Protection Agency (1976, 1980, 1985a), U.S. Federal Water Pollution Control Administration (1968), Willingham (1976), and Willingham et al. (1979).

The criteria presented herein supersede previous saltwater aquatic life water quality criteria for ammonia 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 1983a), which may include not only site-specific criterion concentrations and mixing zone considerations (U.S. EPA, 1983b), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA 1985b). This criterion does not apply to saltwater lakes. These water bodies may require development of site-specific water quality criteria. The latest comprehensive literature search for information for this document was conducted in June, 1986; some more recent information has been included.

## ACUTE TOXICITY TO SALTWATER ANIMALS

The acute toxicity of ammonia to saltwater animals has been studied in crustaceans, bivalve mollusks, and fishes. Acute values are summarized in Table 1 for 21 species in 18 genera. The winter flounder, Pseudopleuronectes americanus, represents the most sensitive gems, with a Species Mean Acute Value (SMAV) of 0.492 (Cardin 1986). Fourteen (eight fish, five crustaceans and one mollusc) of the remaining 17 genera have Genus Mean Acute Values within the order of magnitude of that for the winter flounder. The three most tolerant species are mollusks. The SMAVs are 19.1 mg/L for the Eastern oyster, Crassostrea virginica, 5.36 mq/L for the quahog clam, Mercenaria mercenaria, and 3.08 mg/L for the brackish water clan, Rangia cuneata. Except for these mollusks, there is no phyletic pattern in acute sensitivity to ammonia. Fishes and crustaceans are well represented among both the more sensitive and the more tolerant species tested.

Few consistent trends or patterns are evident in the acute toxicity values cited in Table 1 with respect to biological or environmental variables. Contributing to this, in part, is test variability. This is evident in multiple tests with the same species, even when conducted under closely comparable conditions. Variability in acute toxicity values for ammonia may reflect differences in coalition of the test organisms, changes in the exposure conditions during testing, particularly pH, and variance incurred through calculation of un-ionized ammonia concentrations. As noted in the Introduction, pH has a strong influence on the concentration of un-ionized ammonia in water, such that a variation of ± 0.1 pH unit during the test my result in ± 25% variation in the $NH_3$ exposure concentration. The $NH_3$ exposure concentrations are calculated values dependent on accurate measurement of exposure pH. However, pH monitoring during a test may not always detect potentially significant pH excursions. Also, non-systematic errors on the order of ± 0.03 pH unit may also occur with seawater pH measurements due to variation in the liquid junction potential between and within electrode pairs. In addition to these sources of error, interpretation of test results should consider known replicability of toxicity tests. Intra- and inter-laboratory comparisons of acute toxicity test results using saltwater species show LC50s may differ by as much as a factor of two for the same chemical tested with the same species (Hansen 1984; Schimmel 1986). In light of all these sources of variability, LC50s for un-ionized ammonia are in this document considered similar unless they differ by at least a factor of two.

Few marked differences are evident in the acute toxicity of ammonia with respect to differences in life stage or size of the test organism. Yolk-sac larval striped bass (Morone saxatilis) seem slightly less sensitive to un-ionized ammonia (LC50s - 0.70 and 1.09 mg/L) than 9 or 10 day old post-yolk sac larvae (LC50s - 0.33 and 0.58 mg/L) (Poucher 1986). Juvenile striped bass also seem less sensitive than post yolk-sac larvae (LC50s range from 0.91 to 1.66 mg/L) in tests by EA Eng. (1986) and Hazel et al. (1971). Acute values for striped mullet (Mugil cephalus) suggest a factor of two decrease in sensitivity (LC50 - 1.19 vs. 2.38 mg/L) to ammonia with increase in weight from 0.7 to 10.0g (Venkataramiah et al. 1981). Larval grass shrimp (Palaemonetes pugio) appear to be more acutely sensitive (LC50 - 1.06) (EA Eng. 1986) than juveniles and adults (LC50 - 2.57) (Fava et al. 1984), although the contrasting life stages were tested at different salinities. A slight decrease in the acute sensitivity of Eastern oysters, Crassosrtrea virginica, is evident between 13 and 17 mm (LC50 = 8.6 to 15 mg/L) and 42 to 62 mm (LC50 = 24 to 43 mg/L) (Epifano and Srna 1975). No size related difference in acute sensitivity to ammonia was seen between 4.7 to 5.2 mm and 28 to 32 mm quahog clams, (Mercenaria mercenaria) (Epifanio and Srna 1975).

Several data sets in Table 1 permit an evaluation of the influence of salinity, temperature and pH on the acute toxicity of ammonia to saltwater animals. Few differences are evident in acute toxicity at different salinities in tests with similar life stages and similar pH and temperature conditions. Mysids (Mysidopsis bahia) have overlapping LC50s at four salinities in tests at pH > 7.8 and 25°C. At 10 to 11 g/kg salinity, $NH_3$ LC50s range from 1.04 to 3.19 mg/L; at 20 g/kg, 2.82 to 2.87 mg/L; at 30 g/kg, 1.47 to 3.41 mg/L (Cardin 1986); and at 14 to 18 g/kg, 0.92 to 1.68 mg/L (EA Eng. 1986). At pH 7.0, the LC50 was lower at a low salinity by a factor of 2.2 (Cardin 1986) (LC50 = 0.23 mg/L at 11 g/kg; 0.50 and 0.54 mg/L at 31 g/kg salinity). Acute values for larval inland silversides (Menidia beryllina) tested at pH 8 and 25°C are approximately a factor of 2 lower at 11 g/kg salinity with the LC50 = 0.88 mg/L, relative to 1.94 mg/L at 19 g/kg and 1.77 mg/L at 30 g/kg salinity (Poucher 1986). However, at pH 7 and 9, the LC50s for these larvae are slightly higher at 11 g/kg than at 31 g/kg salinity (by a factor of 1.7 and 1.5, respectively, comparing flow through test values only). Atlantic silverside (Menidia menidia) juveniles at pH 8 and $\geq$ 20°C have $NH_3$ LC50s ranging from 0.97 to 1.24 mg/L at 9 to 10 g/kg salinity (EA Eng. 1986) which corresponds well with the 0.98 mg/L value reported at 30 g/kg salinity by Fava et al. (1984). Acute values overlap for two fishes tested at low and high salinities by Hazel et al. (1971). For the three spined stickleback (Gasterosteus aculeatus), LC50s range from 2.09 to

2.75 mg/L at approximately 11 g/kg salinity and 1.68 to 5.6 mg/L at approximately 34 g/kg. With juvenile striped bass (Morone saxatilis), LC50s are 0.91 (EA Eng. 1986) and 1.0 to 1.68 mg/L at approximately 11 g/kg salinity; 0.75 and 1.4 mg/L at approximately 34 g/kg (Hazel et al. 1971).

Temperature also has little influence on the acute toxicity of ammonia with most saltwater animals tested. Acute values for thermally acclimated larval inland silverside (Menidia beryllina) tested at three temperatures and at similar pH and salinity (8.0 pH; 31 g/kg salinity) differ by less than a factor of 2. For this species tested at 18°C, the LC50 is 0.98 mg/L; at 25°C, LC50s are 1.75 and 1.77 mg/L; and at 32.5°C, the LC50 is 1.7 mg/L (Poucher 1986). The LC50 for thermally acclimated larval sheepshead minnow (Cyprinodon variegatus) at 13°C is 2.10 mg/L; at 25°C, 2.79 mg/L; and at 32.5°C, 3.5 mg/L (Poucher 1986). Acute values for juvenile striped bass (Morone saxatilis) tested at 15°C and 23°C overlap when tested at approximately 11 g/kg salinity and differ by less than a factor of 2 at approximately 34 g/kg salinity (Hazel et al. 1971). With three spined stickleback (Gasterosteus aculeatus) there was little difference in sensitivity to $NH_3$ at 15°C (LC50 = 2.75 mg/L) and 23°C (LC50 = 2.09 mg/L) at approximately 11 g/kg salinity, but in tests at approximately 34 g/kg, sensitivity was about 2 times greater at the higher temperature (at 23°C, LC50 = 1.68 and 2.7 mg/L; at 15°C, LC50 = 4.35 and 5.6 mg/L) (Hazel et al. 1971).

Several data sets on the effect of pH on the toxicity of un-ionized ammonia suggest that [illegible] e the data on freshwater species, the pH-toxicity relationship is not consistent between species. Text Table 1 summarizes LC50s of acute tests conducted at different pH conditions. Results are

Text Table 1.

Acute Toxicity of Un-ionized Ammonia to the Prawn (*Macrobrachium rosenbergii*), Mysid (*Mysidopsis bahia*), Larval Inland Silverside (*Menidia beryllina*), and Juvenile Atlantic Silverside (*Menidia menidia*), at Different pH Conditions. Toxicity expressed as LC50, mg $NH_3$/L. Flow-through test results underlined, mean temperature and salinity conditions indicated.

| pH | Prawn (Armstrong et al. 1978) 28°C, 12 g/kg | Mysid (Cardin 1986) 24.5°C, 11g/kg | (Cardin 1986) 25°C, 31 g/kg | (EA Eng. 1986) 20°C, 31 g/kg | Inland Silverside (Poucher 1986) 25°C, 11 g/kg | (Poucher 1986) 25°C, 31 g/kg | Atlantic (EA Eng. 1986) 22°C, 9.5 g/kg |
|---|---|---|---|---|---|---|---|
| 6.5-6.9 | 0.38 | - | - | - | - | - | - |
| 7.0-7.4 | - | <u>0.28</u> | <u>0.50</u>, 0.54 | 0.27 | <u>1.64</u> | <u>0.93</u>, <u>0.97</u>, <u>1.06</u> | 0.97 |
| 7.5-7.9 | 0.95 | 1.18 | 1.47 | 0.40, 0.92, 1.0 | - | 1.40 | <u>1.05</u>, 1.32 |
| 8.0-8.4 | 1.3 | <u>1.04</u>, 3.19 | <u>1.70</u>, 2.49 2.98, 3.41 | 0.76 | <u>0.88</u> | <u>1.77</u>, 1.75 | 0.97, 1.07, 1.10, 1.24 |
| 8.5-8.9 | - | - | <u>2.76</u>, 0.77 | 1.51, 1.68 | - | 1.08 | 1.47 |
| 9.0-9.4 | - | <u>2.02</u> | - | - | <u>1.16</u> | <u>0.75</u>, 0.49 | 1.21 |

segregated by the temperature and salinity conditions of the tests to preclude variability from these sources; LC50s also are listed by author so any interlaboratory variability may be recognized. For the two invertebrate species, the acute sensitivity to $NH_3$ is greater (> factor 2) at low pH for the prawn (pH 6.83) (Armstrong et al. 1978) and for the mysid (pH 7.0) (Cardin 1986; EA Eng. 1986), than at higher pH values. This response with mysids was consistent at low and high salinity. The two fishes tested differ from the mysid and prawn in their response to pH. Larval inland silverside (Menidia beryllina) do show increased acute sensitivity to ammonia as pH decreases from 8 to 7, but differ from the mysid response at pH 9.0, with appreciably increased sensitivity (> factor of 2) in 31 g/kg salinity. In contrast, in 11 g/kg salinity water, inland silverside have a nearly two-fold decrease in acute sensitivity at pH 7.0, while mysids have a two-fold increase in acute sensitivity at pH 7.0. A further contrast exists in the response of juvenile Atlantic silverside (Menidia menidia), with test pH over the range of 7.0 to 9.0 having little effect on the acute toxicity of ammonia (EA Eng. 1986). The influence of pH on ammonia toxicity in these two saltwater fishes is also a marked contrast with the response of several freshwater fishes (Erickson 1985) and may reflect basic differences in osmotic and ionic regulatory physiology which could influence their response to elevated external ammonia concentrations of over a range of pH, salinity and temperature conditions.

EPA believes that the data available on all water quality-toxicity relationships for un-ionized ammonia are insufficient to conclude that any of these factors, when acting alone, has a consistent major influence on $NH_3$ toxicity in salt water. Therefore, a water quality dependent function was not derived for the Final Acute Value for saltwater organisms and Genus Mean Acute Values (Table 3) have been used to calculate the Final Acute Value.

The 18 available saltwater Genus Mean Acute Values range from 0.492 mg $NH_3$/L for Pseudopleuronectes to 19.102 mg $NH_3$/L for Crassostrea, a factor of less than 100. Acute values are available for more than one species in three genera. The range of Species Mean Acute Values within two of these genera is less than a factor of 1.2; in the remaining genus, they differ by a factor of 4.5. Eighty-eight percent of the Genus Mean Acute Values were within a factor of ten and 71 percent were a factor of five of the acute value for Pseudopleuronectes. A saltwater Final Acute Value of 0.465 mg $NH_3$/L was obtained using the Genus Mean Acute Values in Table 3 and the calculation procedure described in the Guidelines. This value is slightly lower than Species Mean Acute Value of 0.492 mg/L for winter flounder.

## CHRONIC TOXICITY TO SALTWATER ANIMALS

Chronic toxicity tests have been conducted on ammonia with twelve freshwater and saltwater species of aquatic organisms (Table 2). Of the ten freshwater species tested, two are cladocerans and eight are fishes. The details of the results of the freshwater tests are discussed in the "Ambient Water Quality Criteria for Ammonia - 1984" (U.S. EPA 1985a). In saltwater, a life-cycle toxicity test has been conducted with the mysid, Mysidopsis bahia, and an early life-stage test has been completed with the inland silverside, Menidia beryllina (Table 2).

The effect of ammonia on survival, growth and reproduction of M. bahia was assessed in a life-cycle toxicity test lasting 32 days (Cardin 1986). Survival was reduced to 35 percent of that for controls and length of males and females was significantly reduced in 0.331 mg $NH_3$/L. Although reproduction was markedly diminished in this concentration, it did not differ significantly from controls. Lengths of females were significantly reduced in 0.163 mg/L, but this is not considered biologically significant since reproduction was not affected. No significant effects on mysids were detected at 0.092 mg/L. The chronic limits are 0.163 and 0.331 mg/L for a chronic value of 0.232. The Acute Value from a flow-through test conducted at similar coalitions (7.95 pH, 26.5°C, 30.5 g/kg salinity) with M. bahia is 1.70 mg/L which results in an acute-chronic ratio of 7.2 with this species.

The effect of ammonia on survival and growth of the inland silverside (Menidia beryllim) was assessed in an early life-stage test lasting 28 days (Poucher 1986). Fry survival was reduced to 40 percent in 0.38 mg $NH_3$/L, relative to 93% survival of control fish, which is a significant difference. Average weights of fish surviving in concentrations > 0.074 mg/L were significantly less than weights of controls, an effect which persisted as the concentration of ammonia increased. No significant effects were detected in silversides exposed to 0.050 mg/L. Thus, the chronic limits are 0.050 and 0.074 mg/L for a chronic value of 3.061 mg/L. The acute value, derived as the geometric mean of flow-through tests with this fish at full strength sea water between pH 7.0 and 8.0, is 1.30 mg/L, resulting in an acute-chronic ratio of 21.3.

Acute-chronic ratios are available for ten freshwater and two saltwater species (Table 2). Ratios for the saltwater species are 7.2 for the mysid and 21.3 for inland silversides. These saltwater species have similar acute sensitivities to ammonia, with LC50s near the median for the 21 saltwater species tested. The acute-chronic ratios for the freshwater species vary from 1.4 to 53, so they should not be directly applied to the derivation of a Final Chronic Value. Guidance on how to interpret and apply ratios from tests with freshwater species to derive the freshwater criterion for ammonia has been detailed in U.S. EPA 1985a which should be consulted. This document concludes that: (1) acute-chronic ratios of freshwater species appear to increase with decrease in pH; (2) data on temperature effects on the ratios ace lacking; and (3) acute-chronic ratios for the most acutely and chronically sensitive species are technically more applicable when trying to define concentrationa chronically acceptable to acutely sensitive species. Therefore, mean acute-chronic ratios were selected from freshwater tests with species whose chronic sensitivity was less than or equal to the median conducted at pH > 7.7. These included the channel catfish, with a mean acute-chronic ratio of 10; bluegill, 12; rainbow trout, 14; and fathead minnow, 20. The mean acute-chronic ratios for these four freshwater and the two saltwater species are within a factor of 3. The geometric mean of these six values, 13.1, which divided into the Final Acute Value of 0.465 mg/L yields the Final Chronic Value of 0.035 mg $NH_3$/L.

## TOXICITY TO AQUATIC PLANTS

Nitrogen in the saltwater environment is an important nutrient affecting primary production, the composition of phytoplankton, macroalgal and vascular plant communities, and the extent of eutrophication. Ammonia is an important part of nitrogen metabolism in aquatic plants, but excess ammonia is toxic to saltwater plants (Table 4). Limited data on mixed populations of saltwater benthic microalgae (Admiraal 1977) show that ammonia is more toxic at high than at low pH (Admiraal 1977). This suggests that toxicity may be primarily due to $NH_3$ rather than $NH_4^+$.

Information on the toxicity of ammonia to saltwater plants is limited to tests on ten species of benthic diatoms and on the red macroalgal species, _Champia parvula._ A concentration of 0.247 mg $NH_3$/L retarded growth of seven species of benthic diatoms (Admiraal 1977). A concentration of 0.039 mg/L reduced reproduction of _Champia parvula_ gametophytes; no effect was observed at 0.005 mg/L (Thursby 1986). Tetrasporophytes of _C. parvula_ exposed to 0.005 to 0.026 mg/L for 14 days reproduced less but grew faster; no effect was observed at 0.003 mg/L.

OTHER DATA

A number of researchers have studied the effects of ammonia under test conditions that differed from those applicable to acute and chronic test requirements as specified in the Guidelines (Table 4). Animals studied included rotifers, nemertine worms, echinoderms, mollusks, arthopods, polychraetes, and fishes. Concentrations affecting the species tested are generally greater than than Final Acute Value and are all greater than the Final Chronic Value.

Among the lower invertebrates, Brown (1974) found the time to 50 percent mortality of the nemertine worm, Cerebratulus fuscus, exposed to 2.3 mg $NH_3$/L is 106 minutes. In the rotifer, Brachionus plicatilis, the 24-hr LC50 is 20.9 mg $NH_3$/L, the net reproduction rate was reduced 50 percent by 9.6 mg/L, and the intrinsic rate of population increase was reduced 50 percent by 16.2 mg/L (Yu and Hirayama 1986).

In tests with mollusks, the rate of removal of algae (Isochryris galbana) from suspension (filtration rate) was reduced > 50% during a 20-hr exposure to 0.16 and 0.32 mg $NH_3$/L in juvenile and adult quahog clan (Mercenaria mercenaria) and to 0.08 mg/L in juvenile eastern oysters (Crassostrea virginica) (Epifanio and Srna 1975). The rate of ciliary beating in the mussel, Mytilus edulis, is reduced from 50 percent to complete inhibition in < 1 hour by 0.097 to 0.12 mg/L (Anderson et al. 1978). Excretion of ammonia is inhibited in channeled whelk (Busycon canaliculatum), common rangia (Rangia cuneata), and a nereid worm (Nereis succinea) exposed to sublethal concentrations of 0.37, 0.85 and 2.7 mg/L, respectively (Mangum et al. 1978). The authors conclude that ammonia crosses the excretory epithelium in the ionized form, ad that process is linked to

$Na^+$ and $K^+$ ATPases. In the common bloodworm (Glycera dibrachiata), Sousa et al. (1977) found no competition exists between $NH_3$ and oxygen in binding hemoglobin.

Ammonium chloride (about 0.01 mg $NH_3$/L) exposure of unfertilized eggs of the sea urchins, Lytechinus pictus, Strongylocentrotus purpuratus, and S. drobachiensis increased the amount and rate of release of "fertilization acid" above that occurring post-insemination (Johnson et al. 1976; Paul et al. 1976). Exposure of unfertilized sea urchin (L. pictus) eggs to $NH_4Cl$ resulted in stimulation of the initial rate of protein synthesis, an event that normally follow fertilization (Winkler and Grainger 1978). Activation of unfertilized L. pictus eggs by $NH_4Cl$ exposure (ranging from 0.005 to 0.1 mg $NH_3$/L was demonstrated by an increase in intracellular pH (Shen and Steinhardt 1978; Steinhardt and Mazia 1973). Ammonia treatment activated phosphorylation of thymidine and synthesis of histones in unfertilized eggs of the sea urchin S. purpuratus (Nishioka 1976). Premature chromosome condensation was induced by ammonia treatment of eggs of L. pictus and S. purpuratus (Epel et al. 1974: Krystal and Poccia 1979; Wilt and Mazia 1974). Ammonium chloride treatment (0.01 mg $NH_3$/L) of S. purpuratus and S. drobachienris fertilized eggs resulted in absence of normal calcium uptake following insemination, but did not inhibit calcium uptake if ammonia treatment preceded insemination (Paul and Johnston 1978).

In exposures of crustaceans, the 7-day LC50 is 0.666 mg $NH_3$/L for the copepod, Euclaanus elongatus, while 38 percent of the E. pileatus died after 7 days in 0.706 mg/L, (Venkataramiah et al. 1982). No sargassum shrimp (Latreutes fucorum) died after 21 days in < 0.44 mg/L (Venkataramiah et al. 1982). The EC50 bared on reduction in growth of white shrimp (Penaeus setiferus) after three weeks of exposure is 0.72 mg/L (Wickens 1976). The eight-day LC50 is 1.79 mg/L for the American lobster (Homarus americanus) (Delistraty et al. 1977). When blue crabs (Callinectes sapidus) were moved from water of 28 g/kg salinity to water of 5 g/kg, a doubling of ammonia excretion rate occurred; addition of excess $NH_4Cl$ to the low salinity water inhibited ammonia excretion and decreased net acid output (Mangum et al. 1976). Wickins (1976) found that the time to 50 percent mortality for the prawn, Macrobrachium rosenbergii, decreased from 1700 minutes at 1.7 mg/L to 560 minutes at 3.4 mg/L. In a six-week test with this prawn, growth was reduced 32 percent at 0.12 mg/L (Wickins 1976).

The relationship between decrease in toxicity of un-ionized ammonia with increase in pH seen in 96-hour tests with the prawn (Macrobrachium rosenbergii) is also exhibited in data from tests lasting 24 and 144 hours (Table 4) (Armstrong et al. 1978). Prawns were three times more sensitive to $NH_3$ at pH 6.83 than at 7.6. Above pH 7.6, the decrease in acute toxicity was not as great, declining only by a factor of 1.7 at pH 8.34. A similar effect of low pH was seen with growth of the prawn, which after seven days at pH 7.60 was reduced in 0.63 mg/L and at pH 6.83 by 0.11 mg/L (Armstrong et al. 1978).

Few "other data" are available on the effects of ammonia on saltwater fishes (Table 4). In three saltwater tests lasting 24 hours, the LC50s for chinook salmon (Oncorhynchus tshawytscha) ranged from 1.15 to 2.19 mg $NH_3$/L (Harader and Allen 1983). The 24-hr LC50s from two tests with Atlantic salmon (Salmo salar) were 0.115 and 0.28 mg/L (Alabaster et al. 1979). Mortality of the Atlantic silverside (Menidia menidia) was higher in 0.44 mg/L than the 43 percent control mortality in a 28-day early life-stage test

EA Eng. 1986). The 96-hr LC50 for white perch (*Morone americana*) was [illegible] mg/L in a test at pH 6.0, although this pH is rare in natural salt waters (Stevenson 1977).

## UNUSED DATA

Studies conducted with species that are not resident to North America were not used (Alderson 1979; Arizzi and Nicotra 1980; Brown and Currie 1973; Brownell 1980; Chin 1976; Currie et al. 1973; Greenwood and Brown 1974; Inamura 1951; Nicotra and Arizzi 1980; Oshima 1931; Reddy and Menon 1979; Sadler 1981; Yamagata and Niwa 1982). Other data were not used because exposure concentrations were not reported for un-ionized ammonia and/or data on salinity, temperature, and pH necessary to calculate $NH_3$ concentrations were not available (Binstock and Lecar 1969; Linden et al. 1978; Oshima 1931; Pinter and Provasoli 1963; Pruvasoli and McLaughlin 1963; Sigel et al. 1972; Sousa et al. 1974; Thomas et al. 1980; Zgurvskaya and Kustenko 1968). Data of Hall et al. (1978) were not used since the form of ammonia reported in the results is not stated. Data were also not used if ammonia was a component of an effluent (Miknea 1978; Natarojan 1970; Okaichi and Nishio 1976: Rosenberg et al. 1967; Thomas et al. 1980: Ward et al. 1982). Data reported by Sullivan and Ritacco (1985) were not used because the pH was highly variable between treatments. Data from a report by Curtis et al. (1979) were not used because the salt tested, ammonium fluoride, night have dual toxicity. Data reported by Katz and Pierro (1967) were not used because test exposure time and salinity cited in the summary data table and appendix do not agree. Results of a field study by Shilo and Shilo (1953, 1955) were not used since the ammonia concentration was highly variable. The Ministry of Technology, U.K. (1963) report was not used because the ammonia toxicity data were previously published elsewhere and the relevant information is cited in this document. References were not used if they relate more to ammonia metabolism in saltwater species than to ammonia toxicity; e.g., Bartberger and Pierce, Jr. 1976; Cameron 1986; Girard and Payan 1980; Goldstein and Forster 1961; Goldstein et al. 1964; Grollman 1929; Hays et al. 1977; McBean et al. 1966; Nelson et al. 1977; Read 1971; Raguse-Degener et al. 1980; Schooler et al. 1966; Wood 1958. Publications reporting the effects of ammonia as a nutrient in stimulation of primary production were not used, e.g., Byerrum and Benson (1975).

## SUMMARY

All of the following concentrations are un-ionized ammonia ($NH_3$) because $NH_3$, not the ammonium ion ($NH_4^+$), has been demonstrated to be the more toxic form of ammonia. Data used in deriving the criteria are predominantly from tests in which total ammonia concentrations were measured.

Data available on the acute toxicity of ammonia to 21 saltwater animals in 18 genera showed LC50 concentrations ranging from 0.23 to 43 mg $NH_3$/L. me winter flounder, Pseudopleuronectes americanus, is the most sensitive species, with a mean LC50 of 0.492 mg/L. The mean acute sensitivity of 88 percent of the species tested is within a factor of ten of that for the winter fluunder. Fisher and crustaceans are well represented among both the more sensitive and more resistant species; mollusks are generally resistant.

Water quality, particularly pH and temperature, but also salinity, affects the proportion of un-ionized ammonia. With freshwater species, the relationship between the toxicity of un-ionized and pH and temperature is similar for most species and was used to derive pH and temperature dependent freshwater criteria for $NH_3$. For saltwater species, the available data provide no evidence that temperature or salinity have a major or consistent influence on the toxicity of $NH_3$. Hydrogen ion concentration does increase toxicity of $NH_3$ at pH below 7.5 in some, but not all species tested; above pH 8, toxicity may increase, decrease, or be little altered as pH increases, depending on species.

The chronic effects of ammonia have been evaluated in tests with two saltwater and ten freshwater species. In a life-cycle test with a myrid, adverse effects were observed at 0.331 mg $NH_3$/L but not at 0.163 mg/L. In an early life-stage test with inland silverribs, adverse effects were observed

at 0.074 mg/L $NH_3$ but not at 0.050 mg/L. Acute-chronic ratios are available for 12 species and range from 1.4 to 53. Ratios for the four most sensitive freshwater species, tested at pH values greater than 7.7, and for the two saltwater species tested, range from 7.2 to 21.3.

Available data on the toxicity of un-ionized ammonia to plants suggests significant effects may occur in benthic diatoms exposed to concentrations only slightly greater than those acutely lethal to salt-water animals. Ammonia at concentrations slightly less than those chronically toxic to animals my stimulate growth and reduce reproduction of a red macroalgal species.

The key research needs that should be addressed in or&r to provide a more complete assessment of toxicity of ammonia to saltwater species are: (1) assess reported pH-toxicity relationships and test other species by conducting additional acute toxicity tests using flow-through techniques and continuous pH control both with and without pH acclimation; (2) determine the effects of water quality variables on acute-chronic ratios by conducting Life-cycle and early life stage tests with saltwater species; (3) investigate temperature influence by additional acute toxicity tests with species that can tolerate both low and high temperature extremes; (4) test the effects of constant total ammonia exposure and cyclic water quality charger to mimic potential tidal ad dial shifts in salinity and pH; (5) test the effects of fluctuating and intermittent exposures with a variety of species; and (6) investigate the total of other water quality variables on ammonia toxicity: e.g., dissolved oxygen and chlorine; and (7) investigate the contribution of $NH_4^+$ to the toxicity of aqueous ammonia solutions to better resolve how the ammonia criterion should be expressed if pH dependence continued to be demonstrated.

## NATIONAL CRITERIA

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms should not be affected unacceptably if the four-day average concentration of un-ionized ammonia does not exceed 0.035 mg/L more than once every three years on the average and if the one-hour average concentration does not exceed 0.233 mg/L more than once every three years on the average. Because sensitive saltwater animals appear to have a narrow range of acute susceptibilities to ammonia, this criterion till probably be as protective as intended only when the magnitudes and/or durations of excursions are appropriately mall.

Criteria concentrations based cm total ammonia for the pH range of 7.0 to 9.0, temperature range of 0 to 35°C, and salinities of 10, 20 and 30 g/kg are provided in Text Tables 2 and 3. These values were calculated by Hampson's (1977) program of Whitfield's (1974) model for hydrolysis of ammonium ions in sea water.

Three years is the Agency's best scientific judgment of the average amount of time aquatic ecosystem should be provided between excursions. The ability of ecosystems to recover differ greatly.

Site-specific criteria may be established if adequate justification is provided. This site-specific criterion may include not only sits-specific criteria concentrations, and mixing zone considerations (U.S. EPA, 1983b), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedances (U.S. EPA 1985b).

Use of criteria for developing water quality-based permit limits and for designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of those criteria (U.S. EPA 1985b). Limited data or other considerations might make their use impractical, in which case one should rely on a steady-state model (U.S. &PA 1986).

## IMPLEMENTATION

Water quality standards for ammonia developed from then criteria should specify use of environmental monitoring methods which are comparable to the analytical methods employed to generate the toxicity data base. Total ammonia may be measured using an automated idophenol blue method, such as described by Technicon Industrial System (1973) or U.S. EPA (1979) method 350.1. Un-ionized ammonia concentrations should be calculated during the dissociation model of Whitfield (1974) as programmed by Hampson (1977). This program was used to calculate most of the un-ionized values for saltwater organisms listed in Table 1 and 2 of this document. Accurate measurement of sample pH is crucial in the calculation of the un-ionized ammonia fraction. The following equipment and procedures were used by EPA in the ammonia toxicity studies to enhance the precision of pH measurements in salt water. The pH meter reported two decimal places. A Ross electrode with ceramic junction was used due to its rapid response time; an automatic temperature compensation probe provided temperature correction. Note that the responsiveness of a new electrode may be enhanced by holding it in sea water for several days prior to use. Two National Bureau of Standards buffer solutions for calibration preferred for their stability were (1) potassium hydrogen phthalate (pH 4.00) and (2) disodium hydrogen phosphate (pH 7.4). For overnight or weekend storage, the electrode was held in salt water, leaving the fill hole open. For daily use, the outer half-cell was filled with electrolyte to the fill hole and the electrode checked for stability. The electrode pair MS calibrated once daily prior to measuring pH of samples; it was never recalibrated during a series of measurements. Following calibration, the electrode was soaked in sea water, of salinity similar to the sample, for at least 15 minutes to achieve chemical equilibrium and a steady state junction potential. When measuring pH, the sample was initially gently agitated or stirred to assure good mixing at the electrode tip, but without entraining air bubbles in the sample. Stirring was stopped to read the meter. The electrode was allowed to equilibrate so the change in meter reading was less than 0.02 pH unit/minute before recording. Following each measurement, the electrode was rinsed with sea water and placed in fresh sea water for the temporary storage between measurements. Additional suggestions to improve precision of saltwater pH measurements may be found in Zirno (1975), Grasshoff (1983), and Butler et al. (1985).

Text Table 2
Water quality criteria for saltwater aquatic life based on total ammonia (mg/L)
Criteria Maximum Concentrations

| | Temperature (°C) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| pH | | | | Salinity = 10 g/kg | | | | |
| 7.0 | 270 | 191 | 131 | 92 | 62 | 44 | 29 | 21 |
| 7.2 | 175 | 121 | 83 | 58 | 40 | 27 | 19 | 13 |
| 7.4 | 110 | 77 | 52 | 35 | 25 | 17 | 12 | 8.3 |
| 7.6 | 69 | 48 | 33 | 23 | 16 | 11 | 7.7 | 5.6 |
| 7.8 | 44 | 31 | 21 | 15 | 10 | 7.1 | 5.0 | 3.5 |
| 8.0 | 27 | 19 | 13 | 9.4 | 6.4 | 4.6 | 3.1 | 2.3 |
| 8.2 | 18 | 12 | 8.5 | 5.8 | 4.2 | 2.9 | 2.1 | 1.5 |
| 8.4 | 11 | 7.9 | 5.4 | 3.7 | 2.7 | 1.9 | 1.4 | 1.0 |
| 8.6 | 7.3 | 5.0 | 3.5 | 2.5 | 1.8 | 1.3 | 0.98 | 0.75 |
| 8.8 | 4.6 | 3.3 | 2.3 | 1.7 | 1.2 | 0.92 | 0.71 | 0.56 |
| 9.0 | 2.9 | 2.1 | 1.5 | 1.1 | 0.85 | 0.67 | 0.52 | 0.44 |
| | | | | Salinity = 20 g/kg | | | | |
| 7.0 | 291 | 200 | 137 | 96 | 64 | 44 | 31 | 21 |
| 7.2 | 183 | 125 | 87 | 60 | 42 | 29 | 20 | 14 |
| 7.4 | 116 | 79 | 54 | 37 | 27 | 18 | 12 | 8.7 |
| 7.6 | 73 | 50 | 35 | 23 | 17 | 11 | 7.9 | 5.6 |
| 7.8 | 46 | 31 | 23 | 15 | 11 | 7.5 | 5.2 | 3.5 |
| 8.0 | 29 | 20 | 14 | 9.8 | 6.7 | 4.8 | 3.3 | 2.3 |
| 8.2 | 19 | 13 | 8.9 | 6.2 | 4.4 | 3.1 | 2.1 | 1.6 |
| 8.4 | 12 | 8.1 | 5.6 | 4.0 | 2.9 | 2.0 | 1.5 | 1.1 |
| 8.6 | 7.5 | 5.2 | 3.7 | 2.7 | 1.9 | 1.4 | 1.0 | 0.77 |
| 8.8 | 4.8 | 3.3 | 2.5 | 1.7 | 1.3 | 0.94 | 0.73 | 0.56 |
| 9.0 | 3.1 | 2.3 | 1.6 | 1.2 | 0.87 | 0.69 | 0.54 | 0.44 |
| | | | | Salinity = 30 g/kg | | | | |
| 7.0 | 312 | 208 | 148 | 102 | 71 | 48 | 33 | 23 |
| 7.2 | 196 | 135 | 94 | 64 | 44 | 31 | 21 | 15 |
| 7.4 | 125 | 85 | 58 | 40 | 27 | 19 | 13 | 9.4 |
| 7.6 | 79 | 54 | 37 | 25 | 21 | 12 | 8.5 | 6.0 |
| 7.8 | 50 | 33 | 23 | 16 | 11 | 7.9 | 5.4 | 3.7 |
| 8.0 | 31 | 21 | 15 | 10 | 7.3 | 5.0 | 3.5 | 2.5 |
| 8.2 | 20 | 14 | 9.6 | 6.7 | 4.6 | 3.3 | 2.3 | 1.7 |
| 8.4 | 12.7 | 8.7 | 6.0 | 4.2 | 2.9 | 2.1 | 1.6 | 1.1 |
| 8.6 | 8.1 | 5.6 | 4.0 | 2.7 | 2.0 | 1.4 | 1.1 | 0.81 |
| 8.8 | 5.2 | 3.5 | 2.5 | 1.8 | 1.3 | 1.0 | 0.75 | 0.58 |
| 9.0 | 3.3 | 2.3 | 1.7 | 1.2 | 0.94 | 0.71 | 0.56 | 0.46 |

Text Table 3
Water quality criteria for saltwater aquatic life based on total ammonia (mg/L)
Criteria Continuous Concentrations

| pH | Temperature (°C) 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|---|
| | **Salinity = 10 g/kg** | | | | | | | |
| 7.0 | 41 | 29 | 20 | 14 | 9.4 | 6.6 | 4.4 | 3.1 |
| 7.2 | 26 | 18 | 12 | 8.7 | 5.9 | 4.1 | 2.8 | 2.0 |
| 7.4 | 17 | 12 | 7.8 | 5.3 | 3.7 | 2.6 | 1.8 | 1.2 |
| 7.6 | 10 | 7.2 | 5.0 | 3.4 | 2.4 | 1.7 | 1.2 | 0.84 |
| 7.8 | 6.6 | 4.7 | 3.1 | 2.2 | 1.5 | 1.1 | 0.75 | 0.53 |
| 8.0 | 4.1 | 2.9 | 2.0 | 1.40 | 0.97 | 0.69 | 0.47 | 0.34 |
| 8.2 | 2.7 | 1.8 | 1.3 | 0.87 | 0.62 | 0.44 | 0.31 | 0.23 |
| 8.4 | 1.7 | 1.2 | 0.81 | 0.56 | 0.41 | 0.29 | 0.21 | 0.16 |
| 8.6 | 1.1 | 0.75 | 0.53 | 0.37 | 0.27 | 0.20 | 0.15 | 0.11 |
| 8.8 | 0.69 | 0.50 | 0.34 | 0.25 | 0.18 | 0.14 | 0.11 | 0.08 |
| 9.0 | 0.44 | 0.31 | 0.23 | 0.17 | 0.13 | 0.10 | 0.08 | 0.07 |
| | **Salinity = 20 g/kg** | | | | | | | |
| 7.0 | 44 | 30 | 21 | 14 | 9.7 | 6.6 | 4.7 | 3.1 |
| 7.2 | 27 | 19 | 13 | 9.0 | 6.2 | 4.4 | 3.0 | 2.1 |
| 7.4 | 18 | 12 | 8.1 | 5.6 | 4.1 | 2.7 | 1.9 | 1.3 |
| 7.6 | 11 | 7.5 | 5.3 | 3.4 | 2.5 | 1.7 | 1.2 | 0.84 |
| 7.8 | 6.9 | 4.7 | 3.4 | 2.3 | 1.6 | 1.1 | 0.78 | 0.53 |
| 8.0 | 4.4 | 3.0 | 2.1 | 1.5 | 1.0 | 0.72 | 0.50 | 0.34 |
| 8.2 | 2.8 | 1.9 | 1.3 | 0.94 | 0.66 | 0.47 | 0.31 | 0.24 |
| 8.4 | 1.8 | 1.2 | 0.84 | 0.59 | 0.44 | 0.30 | 0.22 | 0.16 |
| 8.6 | 1.1 | 0.78 | 0.56 | 0.41 | 0.28 | 0.20 | 0.15 | 0.12 |
| 8.8 | 0.72 | 0.50 | 0.37 | 0.26 | 0.19 | 0.14 | 0.11 | 0.08 |
| 9.0 | 0.47 | 0.34 | 0.24 | 0.18 | 0.13 | 0.10 | 0.08 | 0.07 |
| | **Salinity = 30 g/kg** | | | | | | | |
| 7.0 | 47 | 31 | 22 | 15 | 11 | 7.2 | 5.0 | 3.4 |
| 7.2 | 29 | 20 | 14 | 9.7 | 6.6 | 4.7 | 3.1 | 2.2 |
| 7.4 | 19 | 13 | 8.7 | 5.9 | 4.1 | 2.9 | 2.0 | 1.4 |
| 7.6 | 12 | 8.1 | 5.6 | 3.7 | 3.1 | 1.8 | 1.3 | 0.90 |
| 7.8 | 7.5 | 5.0 | 3.4 | 2.4 | 1.7 | 1.2 | 0.81 | 0.56 |
| 8.0 | 4.7 | 3.1 | 2.2 | 1.6 | 1.1 | 0.75 | 0.53 | 0.37 |
| 8.2 | 3.0 | 2.1 | 1.4 | 1.0 | 0.69 | 0.50 | 0.34 | 0.25 |
| 8.4 | 1.9 | 1.3 | 0.90 | 0.62 | 0.44 | 0.31 | 0.23 | 0.17 |
| 8.6 | 1.2 | 0.84 | 0.59 | 0.41 | 0.30 | 0.22 | 0.16 | 0.12 |
| 8.8 | 0.78 | 0.53 | 0.37 | 0.27 | 0.20 | 0.15 | 0.11 | 0.09 |
| 9.0 | 0.50 | 0.34 | 0.26 | 0.19 | 0.14 | 0.11 | 0.08 | 0.07 |

Table 1. Acute Toxicity of Ammonia to Saltwater Animals

| Species | Life Stage or size | Chem. | Methods[a] | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (C) | Sal (g/kg) | Reference |
|---|---|---|---|---|---|---|---|---|
| Brackish water clam, *Rangia cuneata* | adult | $NH_4Cl$ | S,M | 1.08[b] | 7.95 | 20.2 | 9.2 | EA Eng 1986 |
| Eastern oyster, *Crassostrea virginica* | 42-62 mm | $NH_4Cl$ | S,M | 24-43[c] | 7.70-7.96 | 20 | 27 | Epifanio & Srna 1975 |
| Eastern oyster, *Crassostrea virginica* | 13-17 mm | $NH_4Cl$ | S,M | 8.6-15[c] | 7.70-7.96 | 20 | 27 | Epifanio & Srna 1975 |
| Quahog clam, *Mercenaria mercenaria* | 28-32 mm | $NH_4Cl$ | S,M | 3.1-5.8[c] | 7.70-8.23 | 20 | 27 | Epifanio & Srna 1975 |
| Quahog clam, *Mercenaria mercenaria* | 4.7-5.2 mm | $NH_4Cl$ | S,M | 4.9-8.8[c] | 7.70-8.23 | 20 | 27 | Epifanio & Srna 1975 |
| Copepod, *Eucalanus pileatus* | adult | $NH_4Cl$ | S,M | 0.79[c] | 8.2 | 20.5 | 34 | Venkataramiah et al 1982 |
| Copepod, *Eucalanus elongatus* | adult | $NH_4Cl$ | S,M | 0.867[c] | 8.0 | 20.3 | 34 | Venkataramiah et al 1982 |
| Sargassum shrimp, *Latreutes fucorum* | .045 g | $NH_4Cl$ | S,M | 0.916 | 8.07 | 23.4 | 28 | Venkataramiah et al 1981 |
| Sargassum shrimp, *Latreutes fucorum* | .054 g | $NH_4Cl$ | S,M | 0.638[c] | 8.07 | 23.4 | 28 | Venkataramiah et al 1981 |
| Grass shrimp, *Palaemonetes pugio* | larva | $NH_4Cl$ | S,M | 1.06[b] | 7.92 | 20.4 | 10 | EA Eng 1986 |
| Grass shrimp, *Palaemonetes pugio* | 16-30 mm | $NH_4Cl$ | S,M | 2.57 | 8.1 | 19.3 | 28.4 | Fava et al 1984 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | $NH_4Cl$ | S,M | 0.27[b] | 7.06 | 21.2 | 16.0 | EA Eng 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | $NH_4Cl$ | S,M | 0.40[b] | 7.54 | 19.8 | 14.6 | EA Eng 1986 |

| Species | Life Stage or size | Chem. | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (°C) | Sal (g/kg) | Reference |
|---|---|---|---|---|---|---|---|---|
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | NH4Cl | S,M | 0.92[b] | 7.92 | 19.6 | 16.7 | EA Eng.1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | NH4Cl | S,M | 1.00[b] | 7.92 | 19.8 | 17.6 | EA Eng.1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | NH4Cl | S,M | 0.76[b] | 7.99 | 19.6 | 14.5 | EA Eng.1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | NH4Cl | S,M | 1.51[b] | 8.46 | 21.2 | 16.0 | EA Eng.1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3-5 days old | NH4Cl | S,M | 1.68[b] | 8.92 | 20.6 | 15.6 | EA Eng.1986 |
| Mysid, *Mysidopsis bahia* | juvenile 4 days old | NH4Cl | FT,M | 0.23 | 6.84-7.12 | 24 | 11 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | FT,M | 0.50 | 6.9-7.0[e,f] | 25 | 31 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 0.54 | 6.8-7.2[e] | 25 | 31 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3 days old | NH4Cl | S,M | 1.18 | 7.7 | 25 | 10 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 2 days old | NH4Cl | FT,M | 1.04 | 7.8-8.1[e,f] | 24 | 11 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | FT,M | 1.70 | 7.9-8.0[e,f] | 26.5 | 30.5 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 3 days old | NH4Cl | S,M | 3.19 | 7.8-8.2 | 25 | 10 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 2 days old | NH4Cl | S,M | 2.87 | 7.9-8.1 | 25 | 20 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 2 days old | NH4Cl | S,M | 2.82 | 7.9-8.1 | 25 | 20 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 1.47 | 7.7-8.0 | 25 | 31 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 2.49 | 7.8-8.1 | 25 | 31 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 2.98 | 7.8-8.2 | 25 | 31 | Cardin 1986 |

| Species | Life Stage or size | Chem. | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (c) | Sal (g/kg) | Reference |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 3.41 | 7.9–8.2 [e,f] | 25 | 30 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 2 days old | NH4Cl | FT,M | 2.02 | 9.0–9.2 [e,f] | 24 | 11.5 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 0.77 | 8.7–9.8 [e] | 25 | 31 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | FT,M | 2.76 | 8.8–9.0 [e,f] | 25 | 30 | Cardin 1986 |
| Mysid, *Mysidopsis bahia* | juvenile 1 day old | NH4Cl | S,M | 0.86 [c] | 8.2 | 19.3 | 30.1 | Fava et al.1984 |
| Mysid, *Mysidopsis bahia* | juvenile < 2 day old | NH4Cl | S,M | 0.86 [d] | 8.0–8.2 | 20.0 | 25 | Buikema et al.1981 |
| Prawn, *Macrobrachium rosenbergii* | larvae 3-8 days old | NH4Cl | R,M | 0.38 [g] | 6.83 | 28 | 12 | Armstrong et al.1978 |
| Prawn, *Macrobrachium rosenbergii* | larvae 3-8 days old | NH4Cl | R,M | 0.95 [g] | 7.60 | 28 | 12 | Armstrong et al.1978 |
| Prawn, *Macrobrachium rosenbergii* | larvae 3-8 days old | NH4Cl | R,M | 1.3 [g] | 8.34 | 28 | 12 | Armstrong et al.1978 |
| American lobster, *Homarus americanus* | larva 76 mm | NH4Cl | S,M | 2.21 [c] | 8.1 | 21.9 | 33.4 | Delistraty et al.1977 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 2.09 [c] | 7.58–7.75 | 23 | ~11 | Hazel et al.1971 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 1.68 [c] | 7.95–7.98 | 23 | ~34 | Hazel et al.1971 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 2.7 [c] | 7.93–7.94 | 23 | ~34 | Hazel et al.1971 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 2.75 [c] | 7.85–7.97 | 15 | ~11 | Hazel et al.1971 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 5.68 [c] | 8.06–8.13 | 15 | ~34 | Hazel et al.1971 |
| Three spined stickleback, *Gasterosteus aculeatus* | 32-60 mm. | NH4Cl | S,M | 4.35 [c] | 8.18–8.24 | 15 | ~34 | Hazel et al.1971 |
| Striped mullet, *Mugil cephalus* | 0.4 g | NH4Cl | S,M | 1.23 | 8.08 | 21.0 | 10 | Venkataramiah et al.1981 |
| Striped mullet, *Mugil cephalus* | 0.7 g | NH4Cl | S,[illegible] | 1.19 | 8.14 | 22.0 | 10 | Venkataramiah et al.1981 |

| Species | Life Stage or size | Chem | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (C) | Sal (g/kg) | Reference |
|---|---|---|---|---|---|---|---|---|
| Striped mullet, *Mugil cephalus* | 1.8 g | $NH_4Cl$ | S,M | 1.63 | 7.99 | 21.0 | 10 | Venkataramiah et al 1981 |
| Striped mullet, *Mugil cephalus* | 10.0 g | $NH_4Cl$ | S,M | 2.38 | 8.00 | 23.3 | 10 | Venkataramiah et al 1981 |
| Planehead filefish, *Monocanthus hispidus* | 0.7 g | $NH_4Cl$ | S,M | 0.69 | 8.07 | 23.4 | 28 | Venkataramiah et al 1981 |
| Planehead filefish, *Monocanthus hispidus* | 0.4 g | $NH_4Cl$ | S,M | 0.988 | 8.07 | 23.4 | 28 | Venkataramiah et al 1981 |
| Red drum, *Sciaenops ocellatus* | embryo-larva | $(NH_4)_2SO_4$ | S,M | 0.545[c] | 8.0-8.2 | 25-26 | 28-30 | Holt & Arnold 1983 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 0.14[b] | 7.96 | 10.8 | 8.5 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 0.97[b] | 7.03 | 20.6 | 10.6 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.32[b] | 7.50 | 20.1 | 10.1 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.07[b] | 7.96 | 20.0 | 9.0 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.18[b] | 7.96 | 20.1 | 9.2 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 0.97[b] | 8.00 | 24.8 | 9.7 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.24[b] | 8.00 | 20.2 | 10.2 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | FT,M | 1.05[b] | 7.92 | 24.8 | 9.9 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.47[b] | 8.5 | 21.1 | 10.2 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | juvenile | $NH_4Cl$ | S,M | 1.21[b] | 8.98 | 21.3 | 10.3 | EA Eng 1986 |
| Atlantic silverside, *Menidia menidia* | 33.5 mm | $NH_4Cl$ | S,M | 0.98 | 8.2 | 19.2 | 29.8 | Fava et al 1984 |
| Inland silverside, *Menidia beryllina* | larva 1 week old | $NH_4Cl$ | FT,M | 1.64 | 6.9-7.1[e,f] | 25.0 | 11 | Poucher 1986 |

| Species | Life Stage or size | Chem | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (C) | Sal (g/kg) | Reference |
|---|---|---|---|---|---|---|---|---|
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 0.97 | 6.9-7.1 | 25.5 | 29.5 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 0.93 | 6.9-7.1[e,f] | 25.5 | 30 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | S,M | 1.06 | 7.0-7.2[e] | 26.5 | 31.5 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | S,M | 1.40 | 7.5-7.6[e] | 25.0 | 31 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 0.88 | 7.8-8.1[e,f] | 24 | 11 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 2 weeks old | NH4Cl | FT,M | 0.98 | 7.9-8.1[e,f] | 18 | 30.5 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 1.94 | 7.8-8.0[e,f] | 26 | 19 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 10 days old | NH4Cl | FT,M | 1.77 | 7.9-8.1[e,f] | 25.5 | 30.5 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | S,M | 1.75 | 7.9-8.1[e] | 24.5 | 32 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 1.70 | 7.9-8.1[e,f] | 32.5 | 30 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | S,M | 1.08 | 8.4-8.6[e] | 25 | 33 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 1.16 | 8.9-9.1[e,f] | 24 | 11.0 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | FT,M | 0.75 | 8.9-9.0[e,f] | 26 | 30 | Poucher 1986 |
| Inland silverside, <u>Menidia beryllina</u> | larva 1 week old | NH4Cl | S,M | 0.49 | 9.0-9.1[e] | 26.5 | 31.5 | Poucher 1986 |
| Sheepshead minnow, <u>Cyprinodon variegatus</u> | adult | NH4Cl | S,M | 2.72[b] | 7.97 | 10.3 | 9.8 | EA Eng 1986 |
| Sheepshead minnow, <u>Cyprinodon variegatus</u> | adult | NH4Cl | S,M | 2.36[b] | 7.92 | 20.6 | 10 | EA Eng 1986 |
| Sheepshead minnow, <u>Cyprinodon variegatus</u> | adult | NH4Cl | S,M | 2.91[b] | 7.96 | 20.6 | 10.4 | EA Eng 1986 |
| Sheepshead minnow, <u>Cyprinodon variegatus</u> | adult | NH4Cl | S,M | 3.37[b] | 7.98 | 24.8 | 10.8 | EA Eng 1986 |

| Species | Life Stage or size | Chem | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (C) | Sal (g/kg) | Reference |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sheepshead minnow, *Cyprinidon variegatus* | larva 12.5-14.5 mm. | NH4Cl | FT,M | 2.79 | 7.6-7.9 [e,f] | 25 | 30 | Poucher 1986 |
| Sheepshead minnow, *Cyprinidon variegatus* | larva 12.5-15.5 mm. | NH4Cl | FT,M | 3.5 | 7.6-7.9 [e,f] | 32.5 | 32 | Poucher 1986 |
| Sheepshead minnow, *Cyprinidon variegatus* | larva 13.5-14.5 mm. | NH4Cl | FT,M | 2.10 | 8.0-8.1 [e,f] | 13 | 32.5 | Poucher 1986 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 1.68 [c] | 7.56-7.62 | 15 | ~11 | Hazel et al.1971 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 1.25 [c] | 7.59-7.72 | 23 | ~11 | Hazel et al.1971 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 1.65 [c] | 7.60-7.73 | 23 | ~11 | Hazel et al.1971 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 1.0 [c] | 8.06-8.12 | 15 | ~11 | Hazel et al.1971 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 0.75 [c] | 8.06-8.12 | 15 | ~34 | Hazel et al.1971 |
| Striped bass, *Morone saxatilis* | 20-93 mm. | NH4Cl | S,M | 1.4 [c] | 8.04-8.18 | 23 | ~34 | Hazel et al 1971 |
| Striped bass, *Morone saxatilis* | larva 10 days old | NH4Cl | FT,M | 0.33 | 7.10-7.33 [e,f] | 21.5 | 5 | Poucher 1986 |
| Striped bass, *Morone saxatilis* | larva 1 day old | NH4Cl | S,M | 1.09 | 7.4-7.7 [e] | 18 | 5 | Poucher 1986 |
| Striped bass, *Morone saxatilis* | larva 2-3 days old | NH4Cl | FT,M | 0.70 | 7.2-7.6 [e,f] | 20.5 | 5 | Poucher 1986 |
| Striped bass, *Morone saxatilis* | larva 9 days old | NH4Cl | S,M | 0.58 | 7.25-7.45 [e] | 18 | 5 | Poucher 1986 |
| Striped bass, *Morone saxatilis* | juvenile | NH4Cl | S,M | 0.91 [b] | 7.97 | 20 | 10.2 | EA Eng.1986 |
| White perch, *Morone americana* | juvenile 76 mm | NH4Cl | S,M | 2.13 | 8.0 | 16 | 14 | Stevenson 1977 |
| Spot, *Leiostomus xanthurus* | juvenile | NH4Cl | S,M | 1.04 [b] | 7.92 | 20.4 | 9.3 | EA Eng.1986 |

| Species | Life Stage or size | Chem. | Methods | LC-50 or EC-50 (mg/L NH-3) | pH | Temp (C) | Sal (g/kg) | Reference |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Winter flounder, <u>Pseudopleuronectes americanus</u> | larva 1 day old | NH4Cl | S,M | 0.53 | 7.9-8.1 | 7.5 | 31 | Cardin 1986 |
| Winter flounder, <u>Pseudopleuronectes americanus</u> | larva 1 day old | NH4Cl | S,M | 0.51 | 7.9-8.1 | 7.5 | 31 | Cardin 1986 |
| Winter flounder, <u>Pseudopleuronectes americanus</u> | larva 1 day old | NH4Cl | S,M | 0.44 | 7.9-8.1 | 7.5 | 31 | Cardin 1986 |

[a] FT = flow-through, S = static, R = renewal, M = measured, U = unmeasured.

[b] Recalculated using measured pH values rather than authors' adjusted pH values.

[c] Transformed and/or recalculated using ammonia concentrations (total, NH3-N, NH-N or mM/L), salinity, temperature, and pH reported by the author(s).

[d] calculated as in footnote c using salinity, temperature and pH conditions supplied to ERL-N by the author(s)

[e] NaOH or HCl added to control pH.

[f] 3-5% NH4OH added to control pH.

[g] 96-h or EC-50 from authors' graph.

Table 2. Chronic Toxicity of Ammonia To Aquatic Animals

| Species | Method[a] | pH | Temperature (C) | Salinity (g/kg) | Limits (mg/L NH3) | Chronic Value[b] (mg/L NH3) | Reference |
|---|---|---|---|---|---|---|---|
| | | | **FRESHWATER SPECIES** | | | | |
| Cladoceran, *Ceriodaphnia acanthina* | LC | 7.0-7.5 | 24.0-25.0 | - | 0.199-0.0463 | 0.304 | Mount 1982 |
| Cladoceran, *Daphnia magna* | LC | 8.09 | 22.1 | - | 0.378-0.735 | 0.527 | Russo et al.1985 |
| Cladoceran, *Daphnia magna* | LC | 7.6 | 20.2 | - | 0.53-0.76 | 0.63 | Russo et al.1985 |
| Cladoceran, *Daphnia magna* | LC | 7.63-8.16 | 17.8-20.8 | - | 0.96-1.6 | 1.2 | Reinbold & Pescitelli 1982 |
| Pink salmon, *Oncorhynchus gorbuscha* | ELS | 6.3-6.5 | 4 | - | 0.0024-0.004 | 0.0031 | Rice & Bailey 1980 |
| Pink salmon, *Oncorhynchus gorbuscha* | ELS | 6.3-6.5 | 4 | - | 0.0012-0.0024 | 0.0017 | Rice & Bailey 1980 |
| Rainbow trout, *Salmo gairdneri* | ELS | 7.4 | 14.5 | - | 0.010-0.025 | 0.016 | Calamari et al. 1977 |
| Rainbow trout, *Salmo gairdneri* | LC | 7.69-7.72 | 9.3 | - | 0.0221-0.0439 | 0.0311 | Thurston et al. 1984 |
| Rainbow trout, *Salmo gairdneri* | ELS | 7.4-7.6 | 10-12 | - | 0.06 upper limit | <0.06 | Burkhalter & Kaya 1977 |
| Rainbow trout, *Salmo gairdneri* | ELS | 7.4-7.6 | 10-12 | - | 0.06-0.12 | 0.085 | Burkhalter & Kaya 1977 |
| Atlantic salmon, *Salmo salar* | ELS | 6.7-7.5 | 13 | - | 0.002-0.07 | 0.01 | Samylin 1969 |
| Fathead minnow, *Pimephales promelas* | LC | 8.01 | 24.0 | - | 0.088-0.188 | 0.13 | Thurston 1986 |
| Fathead minnow, *Pimephales promelas* | LC | 7.99 | 24.2 | - | 0.092-0.187 | 0.13 | Thurston 1986 |
| Fathead minnow, *Pimephales promelas* | ELS | 7.63-8.13 | 22.7-26.3 | - | 0.15-0.34 | 0.22 | Swigert & Spacie 1983 |

| Species | Method[a] | pH | Temperature (C) | Salinity (g/kg) | Limits (mg/L NH3) | Chronic Value (mg/L NH3) | Reference |
|---|---|---|---|---|---|---|---|
| Channel catfish, *Ictalurus punctatus* | ELS | 7.6-7.8 | 25.1- | - | 0.073-0.146 | 0.103 | Robinette 1976 |
| Channel catfish, *Ictalurus punctatus* | ELS | 7.34-7.95 | 23.5-28.0 | - | 0.13-0.24 | 0.18 | Swigert & Spacie 1983 |
| Green sunfish, *Lepomis cyanellus* | ELS | 7.9 | 22 | - | 0.22-0.49 | 0.33 | McCormick et al. 1984 |
| Bluegill, *Lepomis macrochirus* | ELS | 7.74 | 22 | - | 0.063-0.136 | 0.0926 | Smith et al. 1984 |
| Smallmouth bass, *Micropterus dolomieui* | ELS | 6.60 | 22.5 | - | 0.0342-0.0558 | 0.0437 | Broderius et al. 1985 |
| Smallmouth bass, *Micropterus dolomieui* | ELS | 7.25 | 22.2 | - | 0.120-0.182 | 0.148 | Broderius et al. 1985 |
| Smallmouth bass, *Micropterus dolomieui* | ELS | 7.83 | 22.3 | - | 0.472-0.760 | 0.599 | Broderius et al. 1985 |
| Smallmouth bass, *Micropterus dolomieui* | ELS | 8.68 | 22.2 | - | 0.433-0.865 | 0.612 | Broderius et al. 1985 |
| **SALTWATER SPECIES** | | | | | | | |
| Mysid, *Mysidopsis bahia* | LC | 7.7-8.0 | 25-27 | 30 | 0.163-0.331 | 0.232 | Cardin 1986 |
| Inland silverside, *Menidia beryllina* | ELS | 7.9-8.0 | 23.5-25.0 | 30-31.5 | 0.050-0.074 | 0.061 | Poucher 1986 |

**Acute-Chronic Ratio**

| Species | Acute Value (mg/L NH3) | Chronic Value (mg/L NH3) | Ratio |
|---|---|---|---|
| **Freshwater Species** | | | |
| Cladoceran, *Ceriodaphnia acanthina* | 1.05 | 0.304 | 3.5 |
| Cladoceran, *Daphnia magna* | 2.68 | 0.527 | 5.1 |
| Cladoceran, *Daphnia magna* | 0.87 | 0.63 | 1.4 |

| Species | Acute Value (mg/L NH3) | Chronic Value (mg/L NH3) | Ratio |
|---|---|---|---|
| Cladoceran, *Daphnia magna* | 4.6 | 1.2 | 3.9 |
| Pink salmon, *Oncorhynchus gorbuscha* | 0.090 | 0.0017 | 53 |
| Pink salmon, *Oncorhynchus gorbuscha* | 0.090 | 0.0031 | 29 |
| Rainbow trout, *Salmo gairdneri* | 0.422 | 0.0311 | 14 |
| Rainbow trout, *Salmo gairdneri* | 0.35 | 0.016 | 22 |
| Fathead minnow, *Pimephales promelas* | 2.54 | 0.13 | 20 |
| Fathead minnow, *Pimephales promelas* | 2.56 | 0.13 | 20 |
| Fathead minnow, *Pimephales promelas* | 1.75 | 0.22 | 8.0 |
| Channel catfish, *Ictalurus punctatus* | 2.42 | 0.103 | 15 |
| Channel catfish, *Ictalurus punctatus* | 1.95 | <0.25 | 8-34 |
| Channel catfish, *Ictalurus punctatus* | 2.12 | 0.283 | 7.5 |
| Channel catfish, *Ictalurus punctatus* | 1.58 | 0.18 | 8.8 |
| Green sunfish, *Lepomis cyanellus* | 2.05 | 0.33 | 6.3 |
| Bluegill, *Lepomis macrochirus* | 1.08 | 0.0926 | 12 |
| Smallmouth bass, *Micropterus dolomieui* | 0.81 | 0.0437 | 19 |
| Smallmouth bass, *Micropterus dolomieui* | 1.14 | 0.148 | 7.7 |

| Species | Acute Value (mg/L NH3) | Chronic Value (mg/L NH3) | Ratio |
|---|---|---|---|
| Smallmouth bass, *Micropterus dolomieui* | 1.30 | 0.599 | 2.2 |
| Smallmouth bass, *Micropterus dolomieui* | 1.77 | 0.612 | 2.9 |
| **Saltwater species** | | | |
| Mysid, *Mysidopsis bahia* | 1.70 | 0.232 | 7.2 |
| Inland silverside, *Menidia beryllina* | 1.30 | 0.061 | 21.3 |

Geometric mean of acute-chronic ratios for channel catfish = 10.0
for bluegill= 12
for rainbow trout = 14 (18 if ELS study included)
for fathead minnow = 20 (15 if ELS study included)
for mysid = 7.2
for inland silverside = 21.3

[a] LC = life cycle, ELS = early life stage.

[b] For details concerning derivation of specific freshwater values see U.S. EPA 1985a Ambient Water Quality Criteria for Ammonia:1984. PB85 2227114 National Technical Information Service, Springfield, VA.

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

| Rank[a] | Genus Mean Acute Value (mg/L NH3) | Species | Species Mean Acute Value (mg/L NH3) | Species Mean Acute-Chronic Ratio |
|---|---|---|---|---|
| | | **SALTWATER SPECIES** | | |
| 18 | 19.102 | Eastern oyster, *Crassostrea virginica* | 19.102 | - |
| 17 | 5.360 | Quahog clam, *Mercenaria mercenaria* | 5.360 | - |
| 16 | 3.08 | Brackish water clam, *Rangia cuneata* | 3.08 | - |
| 15 | 2.932 | Three-spined stickleback, *Gasterosteus aculeatus* | 2.932 | - |
| 14 | 2.737 | Sheepshead minnow, *Cyprinodon variegatus* | 2.737 | - |
| 13 | 2.21 | Lobster, *Homarus americanus* | 2.21 | - |
| 12 | 1.651 | Grass shrimp, *Palaemonetes pugio* | 1.651 | - |
| 11 | 1.544 | Striped mullet, *Mugil cephalus* | 1.544 | - |
| 10 | 1.117 | Inland silverside, *Menidia beryllina* | 1.317 | 21.3[b] |
| | | Atlantic silverside, *Menidia menidia* | 1.050 | - |
| 9 | 1.04 | Spot, *Leiostomus xanthurus* | 1.04 | - |
| 8 | 1.021 | Mysid, *Mysidopsis bahia* | 1.021 | 7.2[c] |
| 7 | 1.012 | Striped bass, *Morone saxatilis* | 0.481 | - |
| | | White perch, *Morone americana* | 2.13 | - |
| 6 | 0.829 | Copepod, *Eucalanus elongatus* | 0.867 | |
| | | Copepod, *Eucalanus pileatus* | 0.793 | |

| Rank[a] | Genus Mean Acute Value (mg/L NH3) | Species | Species Mean Acute Value (mg/L NH3) | Species Mean Acute-Chronic Ratio |
|---|---|---|---|---|
| 5 | 0.826 | Planehead filefish, *Monocanthus hispidus* | 0.826 | - |
| 4 | 0.777 | Prawn, *Macrobrachium rosenbergii* | 0.777 | - |
| 3 | 0.773 | Sargassum shrimp, *Latreutes fucorum* | 0.773 | - |
| 2 | 0.565 | Red drum, *Sciaenops ocellatus* | 0.565 | - |
| 1 | 0.492 | Winter flounder, *Pseudopleuronectes americanus* | 0.492 | - |

[a] Ranked from least sensitive to most sensitive based on Genus Mean Acute Values

[b] Acute-Chronic Ratio calculated from tests with similar exposure parameters (salinity, temperature) and using the geometric mean of LC50 values for pH 7 and 8.

[c] Acute-Chronic Ratio calculated from tests with similar exposure parameters (salinity, pH, and temperature)

Saltwater Final Acute Value = 0.465 mg/L NH3

Saltwater Criterion Maximum Concentration = 0.465 mg/L/2 = 0.233 mg/L NH3

Final Acute-Chronic Ratio = (see text)

Saltwater Final Chronic Value = 0.465 mg/L)/13.1 = 0.035 mg/L NH3

Table 4. Other Data on Effects of Ammonia on Saltwater Organisms

| Species | Chemical | pH | Temperature (°C) | Salinity (g/kg) | Duration | Effect | Concentration (mg/L) | Reference |
|---|---|---|---|---|---|---|---|---|
| Diatom, *Amphiprora paludosa* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 46% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Gyrosigma spencerii* | $NH_4Cl$ | 8.0 | 12 | 15.0 | 3-10 days | 66% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Navicula arenaria* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 25% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Navicula cryptocephala* | $NH_4Cl$ | 8.0 | 12 | 15.0 | 3-10 days | 63% reduction in chlorophyll a | 1.018 | Admiraal 1977 |
| Diatom, *Navicula salinarum* | $NH_4Cl$ | 8.0 | 12 | 15.0 | 3-10 days | 34% reduction in chlorophyll a | 1.234 | Admiraal 1977 |
| Diatom, *Nitzschia closterium* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 77% reduction in chlorophyll a | 1.234 | Admiraal 1977 |
| Diatom, *Nitzschia dissipata* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 62% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Nitzschia dubiformis* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 73% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Nitzschia sigma* | $NH_4Cl$ | 8.0 | 12 | 15.0 | 3-10 days | 66% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Diatom, *Stauroneis constricta* | $NH_4Cl$ | 8.0 | 12 | 33.7 | 3-10 days | 33% reduction in chlorophyll a | 0.247 | Admiraal 1977 |
| Red algae, gametophyte, *Champia parvula* | $NH_4Cl$ | 7.8-7.9 | 22-24 | 30 | 48 hours | reduced reproduction; no effect at 0.005 | 0.039 | Thursby 1986 |
| Red algae, tetrasporophyte, *Champia parvula* | $NH_4Cl$ | 7.8-7.9 | 22-24 | 30 | 14 days | reduced reproduction & stimulated growth no effect at 0.003 | 0.005-0.026 | Thursby 1986 |
| Rotifer, *Brachionus plicatilis* | $NH_4Cl$ | | 23 | 22.8 | 24 hours | LC50 | 20.9[a] | Yu and Hirayama, 1986 |
| Rotifer, *Brachionus plicatilis* | $NH_4Cl$ | 8.5 | 23 | 22.8 | - | 50% reduction in population growth | 16.2[a] | Yu and Hirayama 1986 |
| Rotifer, *Brachionus plicatilis* | $NH_4Cl$ | 8.3 | 23 | 22.8 | - | 50% reduction in net production rate | 9.6[a] | Yu and Hirayama 1986 |
| Nemertine worm, *Cerebratulus fuscus* | $NH_4NO_3$ | 7.9 | 15 | 34 | 106 mins | LT50 | 2.3 | Brown 1974 |

| Species | Chemical | pH | Temperature (C) | Salinity (g/kg) | Duration | Effect | Concentration (mg/L) | Reference |
|---|---|---|---|---|---|---|---|---|
| Blue mussel, *Mytilus edulis* | $NH_4Cl$ | 7.5 | 18 | 34 | <1 hour | 50% reduction in ciliary rate | 0.097 | Anderson et al 1978 |
| Blue mussel, *Mytilus edulis* | $NH_4Cl$ | 7.5 | 18 | 34 | <1 hour | 90% reduction in ciliary rate | 0.11 | Anderson et al 1978 |
| Blue mussel, *Mytilus edulis* | $NH_4Cl$ | 7.5 | 18 | 34 | <1 hour | complete inhibition of cilia | 0.11-0.12 | Anderson et al 1978 |
| Copepod, *Eucalanus elongatus* | $NH_4Cl$ | 8.0 | 20.3 | 30 | 7 days | LC50 | 0.666 | Venkataramiah et al.1982 |
| Copepod, *Eucalanus pileatus* | $NH_4Cl$ | 8.2 | 20.5 | 34 | 7 days | 38% mortality | 0.706 | Venkataramiah et al.1982 |
| Mysid, *Mysidopsis bahia* | $NH_4Cl$ | 7.6 | 29.2 | 3 | 1700 mins | LT50 | 1.7 | Buikema et al 1981 |
| White shrimp, *Penaeus setiferus* | $NH_4Cl$ | - | 28.0 | 30-34 | 3 weeks | EC50 | 0.72* | Wickens 1976 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.0 | 29.2 | 3 | 1700 mins | LT50 | 1.7* | Wickens 1976 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.0 | 29.2 | 3 | 1400 mins | LT50 | 2.7* | Wickens 1976 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.0 | 29.2 | 3 | 560 mins | LT50 | 3.4* | Wickens 1976 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | - | 28.0 | .5-4 | 6 weeks | 30%-40% growth reduction | 0.12* | Wickens 1976 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 6.83 | 28.0 | 12 | 24 hours | LC50 | 0.66 | Armstrong et al 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 6.83 | 28.0 | 12 | 144 hours | LC50 | 0.26 | Armstrong et al 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.60 | 28.0 | 12 | 24 hours | LC50 | 2.10 | Armstrong et al 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.60 | 28.0 | 12 | 144 hours | LC50 | 0.80 | Armstrong et al 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 8.34 | 28.0 | 12 | 24 hours | LC50 | 3.58 | Armstrong et al 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 8.34 | 28.0 | 12 | 144 hours | LC50 | 1.35 | Armstrong et al 1978 |

| Species | Chemical | pH | Temperature (C) | Salinity (g/kg) | Duration | Effect | Concentration (mg/L) | Reference |
|---|---|---|---|---|---|---|---|---|
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 6.83 | 28.0 | 12 | 7 days | reduction in growth rate | 0.11 | Armstrong et al. 1978 |
| Prawn, *Macrobrachium rosenbergii* | $NH_4Cl$ | 7.60 | 28.0 | 12 | 7 days | reduction in growth rate | 0.63 | Armstrong et al. 1978 |
| Grass shrimp, *Palaemonetes pugio* | $NH_4Cl$ | 8.0-8.2 | 20.0 | | 48 hours | LC50 | 0.34-0.53 | Hall et al. 1978 |
| Sargassum shrimp, *Latreutes fucorum* | $NH_4Cl$ | 8.15 | 22.3 | 28 | 21 days | LC0 | 0.44 | Venkataramiah et al. 1982 |
| American lobster, *Homarus americanus* | $NH_4Cl$ | 8.1 | 21.9 | 33.4 | 8 days | LC50 | 1.79[b] | Delistraty et al. 1977 |
| Coho salmon, *Oncorhynchus kisutch* | $NH_4Cl$ | 7.49-7.52 | 15.0 | 25 | 24 hours | LC50 | 0.50 | Katz and Pierro 1967 |
| Chinook salmon, *Oncorhynchus tshawytscha* | $NH_4Cl$ | 7.59 | 11.7 | 0 | 24 hours | LC50 | 0.36 | Harader and Allen 1983 |
| Chinook salmon, *Oncorhynchus tshawytscha* | $NH_4Cl$ | 6.99-7.26 | 12.7 | 5.2 | 24 hours | LC50 | 0.87 | Harader and Allen 1983 |
| Chinook salmon, *Oncorhynchus tshawytscha* | $NH_4Cl$ | 8.4-8.7 | 11.7 | 9.6 | 24 hours | LC50 | 2.19 | Harader and Allen 1983 |
| Chinook Salmon, *Oncorhynchus tshawytscha* | $NH_4Cl$ | 7.3-8.6 | 13.0 | 16.9 | 24 hours | LC50 | 1.38 | Harader and Allen 1983 |
| Chinook Salmon, *Oncorhynchus tshawytscha* | $NH_4Cl$ | 8.29-8.55 | 12.0 | 27.6 | 24 hours | LC50 | 1.15 | Harader and Allen 1983 |
| Atlantic salmon, *Salmo salar* | $NH_4Cl$ | 7.95 | 2.3 | 10.2 | 24 hours | LC50 | 0.28[c] | Alabaster et al. 1979 |
| Atlantic salmon, *Salmo salar* | $NH_4Cl$ | 7.92 | 12.0 | 10.2 | 24 hours | LC50 | 0.115[d] | Alabaster et al. 1979 |
| Atlantic silverside, *Menidia menidia* | $NH_4Cl$ | - | 25.0 | 10 | 28 days | significant increase in mortality | 0.31 | EA Eng. 1986 |
| Striped mullet, *Mugil cephalus* | $NH_4Cl$ | 8.2 | 22.3 | | 21 days | LC50 | 0.951[e] | Venkataramiah et al. 1981 |

[a] Transformed and/or recalculated using ammonia concentrations (total, $NH_4$-N, mM/L, $NH_3$-N).

[b] Calculated using salinity, temperature and pH conditions supplied to ERL-N by the authors.

[c] high d.o. = 9.5 mg/L.

[d] low d.o. = 3.1 mg/L.

[e] Recalculated omitting treatment with highly variable measured concentration.

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