Technical Information Related to Developing a Saltwater Nickel Addendum to the Ambient Water Quality Criteria Document

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Technical Information Related to Developing a Saltwater Nickel Addendum to the Ambient Water Quality Criteria Document (Dissolved and Total Nickel)

INTRODUCTION

National Water Quality Criteria are established by the United States Environmental Protection Agency (USEPA), as mandated by the Clean Water Act of 1977. The Clean Water Act further mandates that these criteria are to be updated as new information becomes available. The National Criteria Document for nickel was published by EPA in 1986, and in subsequent years additional relevant data have been generated. A particular shortcoming of the 1986 document is the long-term Criterion Continuous Concentration (CCC), which was derived using a single saltwater acute-chronic ratio (ACR) and two widely different freshwater ACRs. Few long-term chronic toxicity tests are available which meet the requirements for data to be used in the criteria document for saltwater organisms, and is the reason the 1986 saltwater criterion (CCC) was calculated using only one saltwater ACR.

A literature search yielded new saltwater acute and chronic nickel toxicity data published since 1986. Articles were obtained and reviewed following 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. The new data were used to recalculate nickel criteria for saltwater organisms using exclusively saltwater ACRs. This document presents the data used to derive a new saltwater criteria for nickel and the methods used in their recalculation.

METHODS

A thorough literature search was conducted following standardized literature search procedures. CAS, ECOTOX, ACQUIRE, BIOSIS and selected university data bases were searched using a set of key identifiers to obtain reports and articles published since 1986 (Appendix A). All relevant published articles and reports were identified by title and abstract, and then hard copies were obtained of abstracts and journal articles that were likely to contain useful data. These articles and reports were reviewed and revised acute and chronic saltwater toxicity tables were developed consistent with those in the 1986 nickel criteria document. The revised tables were then used to recalculate the Criterion Maximum Concentration (CMC) and the Criterion Continuous Concentration (CCC), following The Guidelines.

RESULTS

The new acceptable acute and chronic toxicity data for nickel obtained in the literature search were used to update Tables 1, 2 and 3 of the 1986 nickel criteria document (Tables 1a, 2a and 3a, respectively). Based on these findings, all of the nickel concentrations listed in the revised tables should reflect dissolved values or their equivalent. Lussier et al. (1999) compared the total and dissolved metal concentration measurements for nickel (and other metals) in acute saltwater toxicity tests, and determined that the dissolved and total nickel concentrations measured in test solutions were essentially equivalent; thus criteria established for nickel based on measured and nominal concentrations of total nickel in solutions should be equally valid for concentrations based on dissolved nickel. A similar conclusion was reached by Hunt et al. (2002), who compared total and dissolved metal concentration measurements for nickel in acute and chronic saltwater toxicity tests with a fish and two invertebrate species.

CRITERION MAXIMUM CONCENTRATION (CMC)

Twenty saltwater genera, including 18 species of invertebrates and 4 species of fish, were used to calculate the saltwater final acute value (FAV) of 149.2 µg/L listed in the 1986 nickel criteria document. The four most sensitive genera listed in the 1986 criteria document are: *Heteromysis*, *Mercenaria*, *Mysidopsis,* and *Crassostrea*. The Species Mean Acute Values (SMAVs) and Genus Mean Acute Values (GMAVs) for the four most sensitive saltwater species are provided below:

GENUS	**SMAV (▾ g/L)**	**GMAV (▾ g/L)**
Heteromysis formosa	151.7	151.7
Mercenaria mercenaria	310	310
Mysidopsis bigelowi/bahia	634/508	567.5
Crassostrea virginica embryo	1,180	1,180

The literature published since the 1986 criteria document yielded six new genera for which acceptable acute nickel toxicity data now exist, and three new genera for which chronic nickel toxicity data exist. New saltwater genera with acceptable acute values now include: *Americamysis* (formerly *Mysidopsis* - a taxonomic name change since the 1986 nickel criteria document was written), *Mytilus, Cancer, Atherinops, Strongylocentrotus,* and *Haliotus* (Table 1a). The new genera with acceptable chronic values include *Atherinops*, *Mysidopsis* and *Haliotus* (Table 2a). A total of four saltwater genera are now available to recalculate a new saltwater final acute-to-chronic ratio (FACR) value, taking into account the taxonomic change of *Mysidopsis bahia* to the genus *Americamysis.*

The four most sensitive species calculated using the new GMAV's are:

GENUS	**SMAV (▾ g/L)**	**GMAV (▾ g/L)**
*Haliotis rufescens**	145.5	145.5
*Mysidopsis intii**	148.6	148.6
Heteromysis formosa	151.7	151.7
Mercenaria mercenaria	310.0	310.0

*New species acute value

Three of the original four most sensitive genera remain: *Mysidopsis, Heteromysis,* and *Mercenaria*. *Haliotis rufescens,* a commercially important species, replaces *Heteromysis* *formosa* as the most sensitive saltwater species, with *Mysidopsis intii* becoming the second most sensitive saltwater species. *Heteromysis formosa* becomes the third most sensitive species and *Mercenaria mercenaria* the fourth, with the genus *Crassostrea* no longer among the four most sensitive genera. The new GMAV calculated for the genus *Mysidopsis* using the new value for *Mysidopsis intii* (due to the removal of the acute values for *Mysidopsis bahia* and *M. bigelowi* as a consequence of the taxonomic change of both *Mysidopsis bahia* and *Mysidopsis bigelowi* to *Americamysis)* resulted in a GMAV of 148.6 ▼g/L (Table 3a) relative to the original value of 567.5 ▼g/L(U.S. EPA, 1986). The GMAV recalculated for the new genus *Americamysis* is 570.3 ▼g/L, which does not fall within the values of the top four most sensitive species.

Using the updated saltwater acute database and the method of calculation outlined in the Guidelines, the recalculated saltwater nickel FAV is 129.6 ▼g/L; compared to the old FAV of 149.2 ▼g/L. The CMC rounded to two significant figures thus becomes 65 ▼g/L. Both the FAV and CMC values are lower than the existing values for saltwater organisms in the nickel criteria document. A ranked summary of the nickel GMAVs for saltwater using the new data is provided in Figure 1.

CRITERION CONTINUOUS CONCENTRATION (CCC)

One saltwater species (*Mysidopsis bahia*) and two freshwater species (*Daphnia magna* and *Pimephales promelas*), were used to calculate the FACR in the 1986 national criteria document for nickel because there was only one acceptable saltwater ACR available at that time.

ACR Values Used in the 1986 National Nickel Criteria Document to Calculate the CCC

Species	**Acute Value (▼g/L)**	**Chronic Value (▼g/L)**	**Acute Chronic Ratio (ACR)**
Fathead Minnow, *Pimephales promelas* (freshwater)	12,035	338.30	35.58

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Acute Chronic Ratio (ACR)
Water Flea, *Daphnia magna* (freshwater)	2,580	86.55	29.86
Mysid, *Mysidopsis bahia*	508	92.75	5.478
			FACR = 17.99

However, three new chronic nickel toxicity values for three different saltwater organisms have been reported since the 1986 national criteria document was published (Table 2a). The addition of these new chronic values with their corresponding acute toxicity values listed above allows for the calculation of a new CCC using only saltwater species data. The three new genera include a marine fish *Atherinops affinis,* the shrimp *Mysidopsis intii*, and the commercially important bivalve *Haliotis rufescens*. In addition, the taxonomic change of *Mysidopsis bahia* adds the genus *Americamysis* to the list.

ACR Values Used to Calculate the CCC for Saltwater Organisms for the Addendum

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Acute Chronic Ratio (ACR)
Topsmelt *Atherinops affinis*	26,560	4,270	6.220
Mysid *Americamysis bahia**	513	92.75	5.478**
Mysid *Mysidopsis intii*	148.6	22.09	6.727
Red abalone *Haliotis rufescens*	145.5	26.43	5.505
			FACR = 5.960

* Formerly *Mysidopsis bahia* value as reported in the 1986 national criteria document.

** The ACR is not calculated using the new acute value of 513; the ACR value in the 1986 criteria document is used because the Guidelines state that the ACR should be calculated using acute and chronic data from the same test, if possible.

The ACR values calculated using the new acute and chronic nickel toxicity data are all very similar to one another, ranging from 5.478-6.727. This is in contrast to the freshwater ACR values used in the 1986 nickel criteria document, which are 29.86 for *Daphnia magna* and 35.58 for *Pimephales promelas*. The ACRs for the two freshwater species are as much as 6.5 times higher than the saltwater ACR values.

The CCC recommended in this document is calculated by dividing the FAV by the FACR. The FACR calculated as the geometric mean of only the four saltwater ACR values is 5.960, compared to the 17.99 ACR presented in the 1986 criteria document. Therefore, using the new saltwater nickel toxicity data the CCC increases to 22 ▾ g/L, compared to the 8.3 ▾ g/L value calculated in the 1986 criteria document, which relies on the greatly different ACR values for the two freshwater species. Thus, the recalculated CCC using exclusively saltwater genera is nearly three times greater than the CCC in the 1986 criteria document. The recalculated CCC is close to the chronic value of 22.09 ▾ g/L for *M. intii*, and lower than the value of 26.43 ▾ g/L for commercially important abalone *H. rufescens*. A ranked summary of the nickel chronic values for saltwater organisms using the new data is provided in Figure 1 along with the corresponding GMAVs for those species.

OTHER DATA

Other nickel toxicity data deemed not acceptable for use in calculating saltwater criteria per The Guidelines included 48-hour acute nickel toxicity studies using the amphipod, *Ampelisca abdita* (Ho et al. 1999), and 7-day lethality studies with the quahog clam, *Mercenaria mercenaria* (Keppler and Dingwood, 2002) and yellow crab, *Cancer anthonyi* (MacDonald et al. 1988). The 7-day EC_{50} for nickel using *M. mercenaria* was 1,440 ▾ g /L, while no significant mortality was exhibited by yellow crabs up to 10,000 ▾ g/L (Table 6a). The 48-hour acute nickel toxicity tests with *A. abdita* were conducted at three different pH levels. The IC_{50} values associated with the tests were 7,660, >10,100 and 9,400 ▾ g/L at pH 6,7, and 8, respectively. From these data, pH does not appear to substantially increase or decrease nickel toxicity to this particular saltwater species.

UNUSED DATA

The following studies were classified not acceptable following The Guidelines and therefore were not used to calculate the criteria values presented in this document. In the studies conducted by Armstrong et al. (1993) and Hardin et al.(1992) excised tissues were exposed to nickel and transplanted back into the living organism. Only two exposure concentrations were employed in the testing procedures utilized by Lussier et al. (1999), and Taylor et al. (1985) only assessed the toxicity of nickel on two non-resident marine fish species.

NATIONAL CRITERIA

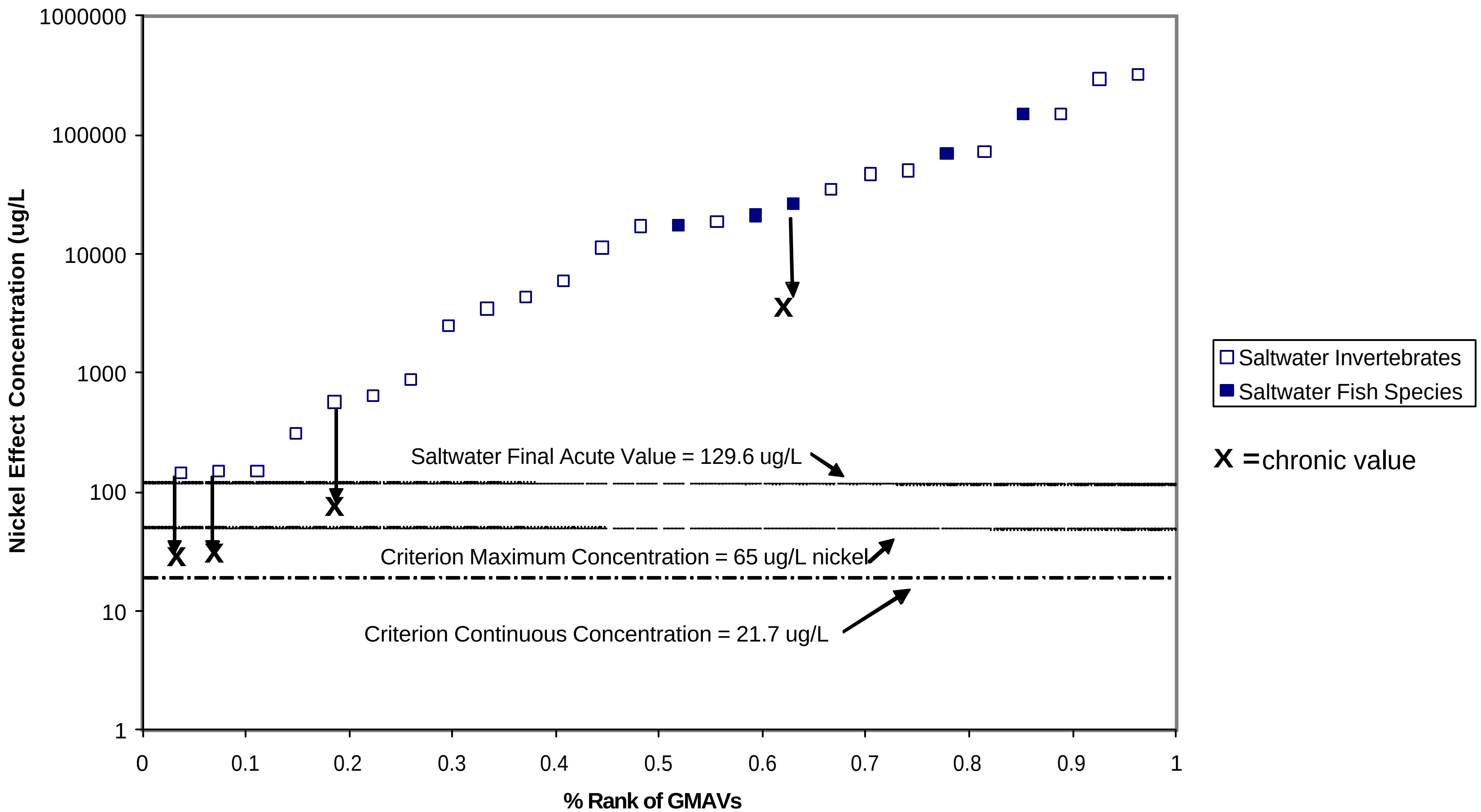
In light of this new information GLEC recommends that EPA consider the following language for its national criterion: The procedures described in the Guidelines, (except possibly when a locally important species is unusually sensitive) should protect saltwater aquatic life if the four-day average dissolved concentration of nickel does not exceed 22 µg/L more than once every three years on the average, and if the 24-hour average dissolved concentration does not exceed 65 µg/L more than once every three years on the average. There are currently insufficient data to establish whether nickel toxicity is salinity-dependent; therefore, the 24-hour average concentration is assumed to be protective at both low and high salinities.

These criteria were developed following U.S. EPA guidance which states that using dissolved nickel provides the most scientifically correct basis upon which to establish water-column criteria for nickel. It is recognized that a small fraction of dissolved nickel in organic-rich water may be less toxic than freely dissolved nickel. On the other hand, some particulate forms of nickel might contribute to nickel loading of organisms, possibly through ingestion.

We also advocate a return interval of three years consistent with the Agency's general recommendation. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria should 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. We recommend 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 USEPA Technical Support Document for Water Quality-Based Toxics Control (document No. 50512-90-001).

Figure 1. Ranked Summary of Saltwater Nickel GMAVs with Correspond Chronic Values of Four Species Graphed below Their Respective GMA



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Stephen, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Service, Springfield, VA, USA.

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APPENDIX A

FOR DATA NOT USED IN THE SALTWATER NICKEL CRITERIA ADDENDUM

Armstrong, N., J. Hardin and D.R. McClay. 1993. Cell-cell interactions regulate skeleton formation in the sea urchin embryo. Development 119, 833-840.

(The tests were conducted without using whole living organisms: tissues were removed exposed to nickel and then transplanted back into the organism.)

Hardin, J., J.A. Coffman, S.D. Black and D.R. McCla 14y. 1992. Commitment along the dorsoventral axis of the sea urchin embryo is altered in response to $NiCl_2$. Development 116, 671-685.

(The tests were conducted without using whole living organisms: tissues were removed exposed to nickel and then transplanted back into the organism.)

Lussier, S.M., W.S. Boothman, S.Poucher, D. Champlin, and A. Helmstetten. 1999. Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms. Environ. Toxicol. Chem. Vol. 18. No.5, pp. 889-898.

(Only two exposure concentrations were included in the testing procedure.)

Taylor, D., B.G. Maddock and G. Mance. 1985. The acute toxicity of nine “grey list” metals (arsenic, boron, chromium, copper, lead, nickel, tin, vanadium and zinc) to two marine fish species: Dab (*Limanda limanda*) and Grey Mullet (*Chelon labrosus*). Aquat. Toxicol. 7: 135-144

(Non-resident species)

Table 1a. Acute Toxicity of Nickel to Aquatic Animals - Saltwater (new data are bolded).

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Polychaete worm (adult), *Nereis arenaceodentata*	S,U	Nickel chloride	-	49,000	49,000	Petrich and Reish 1979
Polychaete worm (adult), *Nereis virens*	S,U	Nickel chloride	20	25,000	25,000	Eisler and Hennekey 1977
Polychaete worm (adult), *Ctenodrilus serratus*	S,U	Nickel chloride	-	17,000	17,000	Petrich and Reish 1979
Polychaete worm (adult), *Capitella capitata*	S, U	Nickel chloride	-	>50,000	>50,000	Petrich and Reish 1979
Mud snail (adult), *Nassarius obsoletus*	S, U	Nickel chloride	20	72,000	72,000	Eisler and Hennekey 1977
Eastern Oyster (embryo), *Crassostrea virginica*	S, U	Nickel chloride	25	1,180	1,180	Calabrese et al. 1973

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Pacific oyster ***Crassostrea gigas***	**S,M**	**Nickel sulfate**	**34 (20▾C)**	**349**	**349**	**Martin et al. 1981**
Clam, *Macoma balthica*	S, U	Nickel chloride	15 (5▾C)	100,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	25 (5▾C)	380,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	35 (5▾C)	700,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	15 (10▾C)	95,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	25 (10▾C)	560,000	-	Bryant et al. 1985

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Clam, *Macoma balthica*	S, U	Nickel chloride	35 (15▾C)	1,100,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	15 (15▾C)	110,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	25 (15▾C)	180,000	-	Bryant et al. 1985
Clam, *Macoma balthica*	S, U	Nickel chloride	35 (15▾C)	540,000	294,500	Bryant et al. 1985
Quahog clam (embryo), *Mercenaria mercenaria*	S, U	Nickel chloride	25	310	310	Calabrese and Nelson 1974
Soft-shell clam (adult), *Mya arenaria*	S, U	Nickel chloride	20	320,000	-	Eisler and Hennekey 1977

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Soft-shell clam (adult), *Mya arenaria*	S, U	Nickel chloride	30	>50,000	320,000	Eisler 1977a
Blue bay mussel ***Mytilus edulis***	**S, M**	**Nickel sulfate**	**34 (17▾C)**	**891**	**891**	**Martin et al. 1981**
Red abalone ***Haliotis rufescens***	**F, M**	**Not reported**	**34 (15▾C)**	**145.5**	**145.5**	**Hunt et al. 2002**
Copepod (adult), *Eurytemora affinis*	S, U	Nickel chloride	30	13,180	-	Lussier and Cardin 1985
Copepod (adult), *Eurytemora affinis*	S, U	Nickel chloride	30	9,593	11,240	Lussier and Cardin 1985
Copepod (adult), *Acartia clausi*	S, U	Nickel chloride	30	3,466	3,466	Lussier and Cardin 1985

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Copepod (adult), *Nitocra spinipes*	S, U	Nickel chloride	7	6,000	6,000	Bengtsson 1978
Mysid (juvenile), *Heteromysis formosa*			30	151.7	151.7	Gentile et al. 1982
Mysid (juvenile) *Mysidopsis bahia* ***Americamysis bahia***	F,M	Nickel chloride	30	508	**-**	Gentile et al. 1982; Lussier et al. 1985
Mysid (juvenile), ***Americamysis*** ***(Mysidopsis) bahia***	S, M	Not reported	30 (20▾C)	IC50: pH 6 - **310** pH 7 - **610** pH 8- **720**	**513**	Ho 1999
Mysid (juvenile), **Americamysis** *(Mysidopsis)* ***bigelowi***	S, M	Nickel chloride	30	634	**634**	Gentile et al, 1982

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Mysid ***Mysidopsis intii***	**F, M**	**Not reported**	**34 (20▾C)**	**148.6**	**148.6**	**Hunt et al. 2002**
Amphipod, *Corophium volutator*	S, U	Nickel chloride	5 (5▾C)	5,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	10 (10▾C)	21,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	15 (5▾C)	18,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	25 (5▾C)	36,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	35 (5▾C)	54,000	-	Bryant et al. 1985

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Amphipod, *Corophium volutator*	S, U	Nickel chloride	5 (10▾C)	8,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	10 (10▾C)	15,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	15 (10▾C)	22,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	25 (10▾C)	24,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	35 (10▾C)	52,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	5 (15▾C)	5,600	-	Bryant et al. 1985

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Amphipod, *Corophium volutator*	S, U	Nickel chloride	10 (15▾C)	16,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	15 (15▾C)	18,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	25 (15▾C)	22,000	-	Bryant et al. 1985
Amphipod, *Corophium volutator*	S, U	Nickel chloride	35 (15▾C)	34,000	18,950	Bryant et al. 1985
Hermit crab (adult), *Pagurus longicarpus*	S, U	Nickel chloride	20	47,000	47,000	Eisler and Hennekey 1977
Dungeness crab *Cancer magister*	**S, M**	**Nickel sulfate**	**34 (15▾C)**	**4,360**	**4,360**	**Martin et al. 1981**

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Starfish (adult), *Asterias forbesii*	S, U	Nickel chloride	20	150,000	150,000	Eisler and Hennekey 1977
Purples sea urchin *Strongylocentrotus purpuratus*	**S, U**	**Nickel chloride**	**34 (15▾C)**	**2,500**	**2,500**	**Garman et al. 1997**
Mummichog (adult), *Fundulus heteroclitus*	S, U	Nickel chloride	6.9	55,000	-	Dorfman 1977
Mummichog (adult), *Fundulus heteroclitus*	S, U	Nickel chloride	21.6	175,000	-	Dorfman 1977
Mummichog (adult), *Fundulus heteroclitus*	S, U	Nickel chloride	20	350,000	149,900	Eisler and Hennekey 1977
Atlantic silverside (larva), *Menidia menidia*	S, U	Nickel chloride	30	7,958	7,958	Cardin 1985

Species	Method[A]	Chemical	Salinity g/kg (temperature)	LC50/EC50 (▾ g/L)[B]	Species Mean Acute Value (▾ g/L)	Reference
Tidewater silverside (juvenile), *Menidia peninsulae*	S, U	Nickel chloride	20	38,000	38,000	Hansen 1983
Striped bass (63 day), *Morone saxatillis*	S, U	Nickel chloride	1	21,000	21,000	Palawski et al. 1985
Spot (juvenile), *Leiostomus zanthurus*	S, U	Nickel chloride	21	70,000	70,000	Hansen 1983
Topsmelt *Atherinops affinis*	**F, M**	**Not reported**	**34 (20▾C)**	**26,560**	**26,560**	**Hunt et al. 2002**

[A] S = static; R = renewal; F = flow-through; M = Measured; U = unmeasured.

[B] Results are expressed as nickel, not as the chemical.

Table 2a. Chronic Toxicity of Nickel to Aquatic Animals - Saltwater (new data are bolded).

Species	Test[A]	Chemical	Salinity (g/kg)	Limits (▾ g/L)[B]	Chronic Value (▾ g/L)	Reference
Mysid, **Americamysis** *(Mysidopsis) bahia*	LC	Nickel chloride	30	61-141	92.74	Gentile et al. 1982; Lussier et al. 1985
Mysid ***Mysidopsis intii***	**LC**	**Not reported**	**34 (20▾C)**	**10.0-48.8**	**22.09**	**Hunt et al. 2002**
Red abalone ***Haliotis rufescens***	**LC**	**Not reported**	**34 (15▾C)**	**21.5-32.5**	**26.43**	**Hunt et al. 2002**
Topsmelt ***Atherinops affinis***	**LC**	**Not reported**	**34 (20▾C)**	**3,240-5,630**	**4,270**	**Hunt et al. 2002**

[A] LC = Life-cycle or partial life-cycle.

[B] Results are based on measured concentrations of nickel; limits are reported No Observed Effect Concentration (NOEC) and Lowest Observed Effect Concentration (LOEC).

Table 3a. Ranked GMAVs with Species Mean Acute Chronic Ratios for the Saltwater Nickel Criteria (new data are bolded).

Rank [A]	**Genus Mean Acute Value (▾ g/L)**	**Species**	**Species Mean Acute Value (▾ g/L)**[B]	**Species Mean Acute-Chronic Ratio**[C]
26	320,000	Soft-shell clam *Mya arenaria*	320,000	
25	294,500	Clam *Macoma balthica*	294,500	
24	150,000	Starfish *Asterias forbessii*	150,000	
23	149,900	Mummichog *Fundulus heteroclitus*	149,900	
22	72,000	Mud snail *Nassarius obsoletus*	72,000	

Rank [A]	Genus Mean Acute Value (▾ g/L)	Species	Species Mean Acute Value (▾ g/L)[B]	Species Mean Acute-Chronic Ratio[C]
21	70,000	Spot *Leiostomus xanthurus*	70,000	
20	>50,000	Polychaete worm *Capitella capitata*	>50,000	
19	47,000	Hermit crab *Pagurus longicarpus*	47,000	
18	35,000	Polychaete worm *Nereis arenaceodentata*	49,00	
		Polychaete worm *Nereis virens*	25,000	
17	**26,560**	**Topsmelt *Atherinops affinis***	**26,560**	**6.220**

Rank [A]	Genus Mean Acute Value (▾ g/L)	Species	Species Mean Acute Value (▾ g/L)[B]	Species Mean Acute-Chronic Ratio[C]
16	21,000	Striped bass *Morone saxatilis*	21,000	
15	18,950	Amphipod *Corophium volutator*	18,950	
14	17,390	Atlantic silverside *Menidia menidia*	7,958	
		Tidewater silverside *Menidia peninsulae*	38,000	
13	17,000	Polychaete worm *Ctenodrilus serratus*	17,000	
12	11,240	Copepod *Eurytemora affinis*	11,240	

Rank [A]	**Genus Mean Acute Value (▾ g/L)**	**Species**	**Species Mean Acute Value (▾ g/L)** [B]	**Species Mean Acute-Chronic Ratio** [C]
11	6,000	Copepod *Nitocra spinipes*	6,000	
10	**4,360**	**Dungeness crab** ***Cancer magister***	**4,360**	
9	3,466	Copepod *Acartia clausi*	3,466	
8	**2,500**	**Purple sea urchin** ***Strongylocentrotus purpuratus***	2,500	
7	**891**	**Bay mussel** ***Mytilus edulis***	**891**	
6	**641.7**	Eastern oyster *Crassostrea virginica*	1,180	

Rank [A]	**Genus Mean Acute Value (▾ g/L)**	**Species**	**Species Mean Acute Value (▾ g/L)**[B]	**Species Mean Acute-Chronic Ratio**[C]
		Pacific oyster ***Crassostrea gigas***	**349**	
5	**570.3**	*Mysid* ***Americamysis*** *bahia*	**513**	**5.478**
		Mysid ***Americamysis*** *bigelowi*	634	
4	310	Quahog clam *Mercenaria mercenaria*	310	
3	151.7	Mysid *Heteromysis formosa*	151.7	
2	**148.6**	**Mysid** ***Mysidopsis intii***	**148.6**	**6.727**

Rank [A]	Genus Mean Acute Value (▾ g/L)	Species	Species Mean Acute Value (▾ g/L)[B]	Species Mean Acute-Chronic Ratio[C]
1	**145.5**	**Red abalone** ***Haliotis rufescens***	**145.5**	**5.505**

A Ranked from most resistant to most sensitive based on Genus Mean Acute Value. Inclusion of “greater than” values does not necessarily imply a true ranking, but does allow use of all genera for which data are available so that the Final Acute Value is not unnecessarily lowered.

B From Table 1

C From Table 2

Table 6a. Other Data on Effects of Nickel on Aquatic Saltwater Organisms (published since the 1986 National Criteria Document).

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration	Reference
Amphipod *Ampelisca abdita*	Nickel	30	48-hours	IC50	7,660 (pH 6.0)	Ho et al. 1999
	Nickel	30	48-hours	IC50	>10,100 (pH 7.0)	Ho et al. 1999
	Nickel	30	48-hours	IC50	9400 (pH 8.0)	Ho et al. 1999
Quahog clam *Mercenaria mercenaria*	Nickel chloride	25	7-days	EC50	1,440	Keppler and Ringwood 2002
Yellow crab *Cancer anthonyi*	Nickel chloride	34	7-Days	mean % mortality	▼ 10,000 (49.3% mortality)	MacDonald et al. 1988

[A] Study determined no differences between dissolved and total measurements for the range-finding tests and used total measurements for the definitive tests.