

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bacteria, <i>Escherichia coli</i>	S,U	Copper sulfate	-	48 hr	Threshold of inhibited glucose use; measured by pH change in media	80	-	Bringmann and Kuhn 1959a
Bacteria, <i>Pseudomonas putida</i>	S,U	Copper sulfate	81.1	16 hr	EC3 (cell numbers)	30	-	Bringmann and Kuhn 1976, 1977a, 1979, 1980a
Protozoan, <i>Entosiphon sulcatum</i>	S,U	Copper sulfate	81.9	72 hr	EC5 (cell numbers)	110	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980a.
Protozoan, <i>Microregia heterostoma</i>	S,U	Copper sulfate	214	28 hr	Threshold of decreased feeding rate	50	-	Bringmann and Kuhn 1959b
Protozoan, <i>Chilomonas paramecium</i>	S,U	Copper sulfate	-	48 hr	Growth threshold	3,200	-	Bringmann and Kuhn 1980b, 1981
Protozoan, <i>Uronema parduezi</i>	S,U	Copper sulfate	-	20 hr	Growth threshold	140	-	Bringmann and Kuhn 1980b, 1981
Protozoa, mixed species	-	-	-	7 days	Reduced rate of colonization	167	-	Cairns et al. 1980
Protozoa, mixed species	S,M,T	Copper sulfate	-	15 days	Reduced rate of colonization	100	-	Buikema et al. 1983
Green alga, <i>Cladophora glomerata</i>	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% down to 0%	120	-	Weber and McFarland 1981
Green alga, <i>Chlamydomonas reinhardtii</i>	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, <i>Chlamydomonas reinhardtii</i>	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, <i>Chlamydomonas reinhardtii</i>	-	Copper sulfate	76	72 hr	Deflagellation	16.3	-	Garvey et al. 1991
Green alga, <i>Chlamydomonas reinhardtii</i>	-	Copper sulfate	76	72 hr	Deflagellation	25.4	-	Garvey et al. 1991
Green alga, <i>Chlorella</i> sp.	S,U	Copper nitrate	-	28 hr	Inhibited photosynthesis	6.3	-	Gachter et al. 1973
Green alga, <i>Chlorella pyrenoidosa</i>	S,U	-	29.4	72 hr	IC50 (cell division rate)	16	-	Stauber and Florence 1989
Green alga, <i>Chlorella pyrenoidosa</i>	S,U	-	14.9	72 hr	IC50 (cell division rate)	24	-	Stauber and Florence 1989
Green alga, <i>Chlorella pyrenoidosa</i>	S,U	Copper sulfate	82	4 hr	Disturbed photosystem II	25	-	Vavilin et al. 1995
Green alga, <i>Eudorina californica</i>	S,U	Copper sulfate	19.1	-	Decrease in cell density	5,000	-	Young and Lisk 1972
Green alga (flagellate cells), <i>Haematococcus</i> sp.	S,U	Copper sulfate	2	24 hr	Inhibited growth during 96 hr recovery period	50	-	Pearlmutter and Buchheim 1983
Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	214	96 hr	Threshold of effect on cell numbers	150	-	Bringmann and Kuhn 1959b
Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	60	72 hr	EC3 (cell numbers)	1,100	-	Bringmann and Kuhn 1980a
Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	34.8	24 hr	EC50 (photosynthesis)	100	-	Starodub et al. 1987

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Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	50	-	Starodub et al. 1987
Green alga, <i>Scenedesmus quadricauda</i>	S,U	Copper sulfate	34.8	24 hr	NOEC (growth)	>200	-	Starodub et al. 1987
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper chloride	14.9	7 days	Growth reduction	50	-	Bartlett et al. 1974
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper sulfate	29.3	72 hr	EC50 (cell count)	19	-	Vasseur et al. 1988
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	41	-	Vasseur et al. 1988
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28	-	Vasseur et al. 1988
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper sulfate	14.9	72 hr	EC50 (cell count)	60	-	Vasseur et al. 1988
Green alga, <i>Selenastrum capricornutum</i>	S,U	Copper sulfate	24.2	72 hr	EC50 (cell count)	28.5	-	Benhra et al. 1997
Green alga, <i>Selenastrum capricornutum</i>	F,U	Copper sulfate	15	24 hr	EC50 (cell density)	21	-	Chen et al. 1997
Diatom, <i>Cocconeis placentula</i>	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% down to <1%	120	-	Weber and McFarland 1981
Phytoplankton, mixed species	S,U	-	-	124 hr	Averaged 39% reduction in primary production	10	-	Cote 1983
Macrophyte, <i>Elodea canadensis</i>	S,U	Copper sulfate	-	24 hr	EC50 (photosynthesis)	150	-	Brown and Rattigan 1979
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	LOEC (primary production)	9.3	-	Hedtke 1984
Microcosm	F,M,T,D	Copper sulfate	200	32 wk	NOEC (primary production)	4	-	Hedtke 1984
Microcosm	F,M,T	Copper sulfate	76.7	96 hr	Significant drop in no. of taxa and no. of individuals	15	-	Clements et al. 1988
Microcosm	F,M,T	Copper sulfate	58.5	10 days	Significant drop in no. of individuals	2.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper sulfate	151	10 days	58% drop in no. of individuals	13.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper sulfate	68	10 days	Significant drop in species richness and no. of individuals	11.3	-	Clements et al. 1990
Microcosm	F,M,T	Copper sulfate	80	10 days	Significant drop in species richness and no. of individuals	10.7	-	Clements et al. 1990
Microcosm	S,M,T	Copper sulfate	102	5 wk	14-28% drop in phytoplankton species richness	20	-	Winner and Owen 1991b
Microcosm	F,M,T	-	160	28 days	LOEC (species richness)	19.9	-	Pratt and Rosenberger 1993

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Dosed stream	F,M,D	Copper sulfate	56	1 yr	Shifts in periphyton species abundance	5.208	-	Leland and Carter 1984
Dosed stream	F,M,D	Copper sulfate	56	1 yr	Reduced algal production	5.208	-	Leland and Carter 1985
Sponge, <i>Ephydatia fluviatilis</i>	S,U	Copper sulfate	200	10 days	Reduced growth by 33%	6	-	Francis and Harrison 1988
Sponge, <i>Ephydatia fluviatilis</i>	S,U	Copper sulfate	200	10 days	Reduced growth by 100%	19	-	Francis and Harrison 1988
Rotifer, <i>Philodina acuticornis</i>	S,U	Copper sulfate	45	48 hr	LC50 (5 <sup>o</sup> C)	1,300	-	Cairns et al. 1978
Rotifer, <i>Philodina acuticornis</i>	S,U	Copper sulfate	45	48 hr	LC50 (10 <sup>o</sup> C)	1,200	-	Cairns et al. 1978
Rotifer, <i>Philodina acuticornis</i>	S,U	Copper sulfate	45	48 hr	LC50 (15 <sup>o</sup> C)	1,130	-	Cairns et al. 1978
Rotifer, <i>Philodina acuticornis</i>	S,U	Copper sulfate	45	48 hr	LC50 (20 <sup>o</sup> C)	1,000	-	Cairns et al. 1978
Rotifer, <i>Philodina acuticornis</i>	S,U	Copper sulfate	45	48 hr	LC50 (25 <sup>o</sup> C)	950	-	Cairns et al. 1978
Rotifer, <i>Brachionus calyciflorus</i>	S, U	Copper sulfate	39.8	24 hr	EC50 (mobility)	200	-	Couillard et al. 1989
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	-	2 hr	LOEC (swimming activity)	12.5	-	Charoy et al. 1995
Rotifer, <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	76	-	Ferrando et al. 1992
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	90	5 hr	EC50 (filtration rate)	34	-	Ferrando et al. 1993a
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	90	6 days	LOEC (reproduction decreased 26%)	5	-	Janssen et al. 1993
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	90	5 hr	LOEC (reduced swimming speed)	12	-	Janssen et al. 1993
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 27%)	5	-	Janssen et al. 1994
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 29%)	5	-	Janssen et al. 1994
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	85	8 days	LOEC (reproduction decreased 47%)	5	-	Janssen et al. 1994
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper chloride	170	35 min	LOEC (food ingestion rate)	100	-	Juchelka and Snell 1994
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	63.2	24 hr	EC50 (mobility)	9.4	-	Porta and Ronco 1993
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	-	90	2 days	LOEC (reproduction decreased 100%)	30	-	Snell and Moffat 1992
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility)	26	-	Snell et al. 1991b

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Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility; 10 <sup>0</sup> C)	18	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility; 15 <sup>0</sup> C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility; 20 <sup>0</sup> C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility; 25 <sup>0</sup> C)	26	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility; 30 <sup>0</sup> C)	25	-	Snell 1991; Snell et al. 1991b
Rotifer (<3 hr), <i>Brachionus rubens</i>	S, U	Copper sulfate	90	24 hr	LC50	19	-	Snell and Persoone 1989b
Rotifer, <i>Keratella cochlearis</i>	S,U	Copper chloride	-	24 hr	LC50	101	-	Borgman and Ralph 1984
Worm, <i>Aeolosoma headleyi</i>	S,U	Copper sulfate	45	48 hr	LC50 (5 <sup>0</sup> C)	2,600	-	Cairns et al. 1978
Worm, <i>Aeolosoma headleyi</i>	S,U	Copper sulfate	45	48 hr	LC50 (10 <sup>0</sup> C)	2,300	-	Cairns et al. 1978
Worm, <i>Aeolosoma headleyi</i>	S,U	Copper sulfate	45	48 hr	LC50 (15 <sup>0</sup> C)	2,000	-	Cairns et al. 1978
Worm, <i>Aeolosoma headleyi</i>	S,U	Copper sulfate	45	48 hr	LC50 (20 <sup>0</sup> C)	1,650	-	Cairns et al. 1978
Worm, <i>Aeolosoma headleyi</i>	S,U	Copper sulfate	45	48 hr	LC50 (50 C)	1,000	-	Cairns et al. 1978
Worm (adult), <i>Lumbriculus variegatus</i>	S,U	Copper sulfate	30		LC50	150		Bailey and Liu, 1980
Worm (7 mg), <i>Lumbriculus variegatus</i>	F,M,T	Copper sulfate	45	10 days	LC50	35	-	West et al. 1993
Tubificid worm, <i>Limnodrilus hoffmeisteri</i>	S,U	Copper sulfate	100		LC50	102		Wurtz and Bridges 1961
Tubificid worm, <i>Tubifex tubifex</i>	R, U	Copper sulfate	245		LC50	158		Khangarot 1991
Snail (11-27 mm), <i>Campeloma decisum</i>	F,M,T	Copper sulfate	45	6 wk	LOEC (mortality)	14.8	-	Arthur and Leonard 1970
Snail, <i>Gyraulus circumstriatus</i>	S,U	Copper sulfate	100		LC50	108		Wurtz and Bridges 1961
Snail, <i>Goniobasis livescens</i>	S,U	Copper sulfate	154	48 hr	LC50	860	-	Cairns et al. 1976
Snail, <i>Goniobasis livescens</i>	S,M,D	Copper sulfate	154	96 hr	LC50	-	390	Paulson et al. 1983
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (5 <sup>0</sup> C)	3,000	-	Cairns et al. 1978
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (10 <sup>0</sup> C)	2,400	-	Cairns et al. 1978

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Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (15 <sup>o</sup> C)	1,000	-	Cairns et al. 1978
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (20 <sup>o</sup> C)	300	-	Cairns et al. 1978
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (25 <sup>o</sup> C)	210	-	Cairns et al. 1978
Snail, <i>Lymnaea emarginata</i>	S,U	Copper sulfate	154	48 hr	LC50	300	-	Cairns et al. 1976
Snail (adult), <i>Juga plicifera</i>	F,M,T	Copper chloride	23	30 days	LC50	6	-	Nebeker et al. 1986b
Snail (adult), <i>Lithoglyphus virens</i>	F,M,T	Copper chloride	23	30 days	LC50	4	-	Nebeker et al. 1986b
Snail, <i>Physa heterostropha</i>	S,U	Copper sulfate	100		LC50	69		Wurtz and Bridges 1961
Freshwater mussel (released glochidia), <i>Actinonaias pectorosa</i>	R,M	Copper sulfate	140	24 hr		132		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Actinonaias pectorosa</i>	R,M	Copper sulfate	150	24 hr		93		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Actinonaias pectorosa</i>	R,M	Copper sulfate	170	24 hr		67		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Actinonaias pectorosa</i>	R,M	Copper sulfate	140	24 hr		42		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Actinonaias pectorosa</i>	R,M	Copper sulfate	170	48 hr		51		Jacobson et al. 1997
Freshwater mussel (1-2 d), <i>Anodonta grandis</i>	S,M,T	Copper sulfate	70	24 hr	LC50	44	-	Jacobson et al. 1993
Freshwater mussel (1-2 d), <i>Anodonta imbecilis</i>	S,M,T	Copper sulfate	39	48 hr	LC50	171	-	Keller and Zam 1991
Freshwater mussel (1-2 d), <i>Anodonta imbecilis</i>	S,M,T	Copper sulfate	90	48 hr	LC50	388	-	Keller and Zam 1991
Freshwater mussel (released glochidia), <i>Lampsilis fasciola</i>	R,M,T	Copper sulfate	170	24 hr		48		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Lampsilis fasciola</i>	R,M,T	Copper sulfate	160	24 hr		26		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Lampsilis fasciola</i>	R,M,T	Copper sulfate	75	24 hr		46		Jacobson et al. 1997

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Freshwater mussel (released glochidia), <i>Lampsilis fasciola</i>	R,M,T	Copper sulfate	170	48 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	185	24 hr		69		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	185	24 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	185	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	170	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	160	24 hr		41		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	150	24 hr		81		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	170	48 hr		16		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Pygranodon grandis</i>	R,M,T	Copper sulfate	170	24 hr		>160		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Pygranodon grandis</i>	R,M,T	Copper sulfate	170	24 hr		347		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Pygranodon grandis</i>	R,M,T	Copper sulfate	50	24 hr		46		Jacobson et al. 1997
Freshwater mussel (1-2 d), <i>Villosa iris</i>	S,M,T	Copper sulfate	190	24 hr	LC50	83	-	Jacobson et al. 1993
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	190	24 hr		80		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	190	24 hr		73		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	185	24 hr		65		Jacobson et al. 1997

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Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	185	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	170	24 hr		75		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		36		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	155	24 hr		39		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	155	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	55	24 hr		55		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	55	24 hr		38		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	50	24 hr		71		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	170	48 hr		66		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	48 hr		46		Jacobson et al. 1997
Zebra mussel (1.6-2.0 cm), <i>Dreissena polymorpha</i>	R,M,T	Copper chloride	268	9 wk	EC50 +F106(filtration rate)	43	-	Kraak et al. 1992

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Zebra mussel (1.6-2.0 cm), <i>Dreissena polymorpha</i>	R,M,T	Copper chloride	268	10 wk	NOEC (filtration rate)	13	-	Kraak et al. 1993
Asiatic clam (1.0-2.1 cm), <i>Coprbicula fluminea</i>	S,M,T	Copper sulfate	64	96 hr (24hr LC50 also reported)	LC50	40	-	Rodgers et al. 1980
Asiatic clam (1.0-2.1 cm), <i>Coprbicula fluminea</i>	F,M,T	Copper sulfate	64	96 hr (24 hr LC50 also reported)	LC50	490	-	Rodgers et al. 1980
Asiatic clam (juvenile), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	78	30 days	43.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (juvenile), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	78	30 days	Stopped shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	78	30 days	13.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (adult), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	71	30 days	25% mortality	16.88	-	Belanger et al. 1990
Asiatic clam (adult), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	78	30 days	Inhibited shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	-	15-16 days	LC50	-	-	Belanger et al. 1991
Asiatic clam (adult), <i>Corbicula fluminea</i>	F,M,D	Copper sulfate	-	19 days	LC100	-	-	Belanger et al. 1991
Asiatic clam (veliger larva), <i>Corbicula manilensis</i>	S,M,T	Copper chloride	-	24 hr	34% mortality	10	-	Harrison et al. 1981, 1984
Asiatic clam (juvenile), <i>Corbicula manilensis</i>	S,M,T	Copper chloride	17	24 hr	LC50	100	-	Harrison et al. 1984
Asiatic clam (veliger), <i>Corbicula manilensis</i>	S,M,T	Copper chloride	17	24 hr	LC50	28	-	Harrison et al. 1984
Asiatic clam (trochophore), <i>Corbicula manilensis</i>	S,M,T	Copper chloride	17	8 hr	LC100	7.7	-	Harrison et al. 1984
Asiatic clam (adult), <i>Corbicula manilensis</i>	F,M,T	Copper chloride	17	7 days	LC50	3,638	-	Harrison et al. 1981, 1984
Asiatic clam (adult), <i>Corbicula manilensis</i>	F,M,T	Copper chloride	17	42 days	LC50	12	-	Harrison et al. 1981, 1984
Asiatic clam (4.3 g adult), <i>Corbicula manilensis</i>	F,M,T	Copper chloride	17	30 days	LC50	11	-	Harrison et al. 1984
Cladoceran, <i>Bosmina longirostrus</i>	S, U	Copper sulfate	33.8		EC50	1.6		Koivisto et al. 1992
Cladoceran (<24 hr), <i>Daphnia ambigua</i>	S,U	Copper sulfate	145	72 hr	LC50	86.5	-	Winner and Farrell 1976
Cladoceran (<24 hr), <i>Daphnia ambigua</i>	S,U	Copper sulfate	145	Life span (ca. 5 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	188		EC50	36.6		Bright 1995



**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	204		EC50	19.1		Bright 1995
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	428		EC50	36.4		Bright 1995
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	410		EC50	11.7		Bright 1995
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	494		EC50	12.3		Bright 1995
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper sulfate	440		EC50	12		Bright 1995
Cladoceran, <i>Ceriodaphnia dubia</i>	S,U	Copper chloride	90	1 hr	NOEC (ingestion)	30	-	Juchelka and Snell 1994
Cladoceran (<24 hr), <i>Ceriodaphnia dubia</i>	S,M,D	Copper sulfate	6-10	48 hr	LC50	-	2.72	Suedel et al. 1996
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	52	Belanger and Cherry 1990
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	76	Belanger and Cherry 1990
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	91	Belanger and Cherry 1990
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	9.5	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	28	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	200	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), <i>Ceriodaphnia dubia</i>	S,M,T,D	Copper nitrate	100	48 hr	LC50	66	60.72	Spehar and Fiandt 1986
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper nitrate	111	10 days	LC50	53	-	Cowgill and Milazzo 1991a
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper nitrate	111	10 days	NOEC (reproduction)	96	-	Cowgill and Milazzo 1991a
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper sulfate	90	-	LOEC (reproduction)	44	-	Zuiderveen and Birge 1997
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper sulfate	90	-	LOEC (reproduction)	40	-	Zuiderveen and Birge 1997
Cladoceran, <i>Ceriodaphnia dubia</i>	R,M,T	-	20	-	IC50 (reproduction)	5	-	Jop et al. 1995
Cladoceran (<24 hrs), <i>Ceriodaphnia reticulata</i>	S, U	Copper chloride	240		EC50	23		Elnabarawy et al. 1986
Cladoceran, <i>Ceriodubia reticulata</i>	S,U	-	43-45		EC50	17		Mount and Norberg 1984
Cladoceran, <i>Daphnia magna</i>	-	Copper sulfate	-	72 hr	EC50 (mobility; 10 <sup>o</sup> C)	61	-	Braginskij and Shcherben 1978

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran, <i>Daphnia magna</i>	-	Copper sulfate	-	72 hr	EC50 (mobility; 15 <sup>o</sup> C)	70	-	Braginskij and Shcherben 1978
Cladoceran, <i>Daphnia magna</i>	-	Copper sulfate	-	72 hr	EC50 (mobility; 20 <sup>o</sup> C)	21	-	Braginskij and Shcherben 1978
Cladoceran, <i>Daphnia magna</i>	-	Copper sulfate	-	72 hr	EC50 (mobility; 30 <sup>o</sup> C)	9.3	-	Braginskij and Shcherben 1978
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	-	16 hr	EC 50 (mobility)	38	-	Anderson 1944
Cladoceran (<8 hr), <i>Daphnia magna</i>	S,U	Copper chloride	-	64 hr	Immobilization threshold	12.7	-	Anderson 1948
Cladoceran (1 mm), <i>Daphnia magna</i>	S,U	Copper nitrate	100	24 hr	EC 50 (mobility)	50	-	Bellavere and Gorbi 1981
Cladoceran (1 mm), <i>Daphnia magna</i>	S,U	Copper nitrate	200	24 hr	EC 50 (mobility)	70	-	Bellavere and Gorbi 1981
Cladoceran, <i>Daphnia magna</i>	S,U	-	100	48 hr	EC50 (mobility)	254	-	Borgmann and Ralph 1983
Cladoceran, <i>Daphnia magna</i>	S,U	-	100	49 hr	EC50 (mobility)	1,239	-	Borgmann and Ralph 1983
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 5 <sup>o</sup> C)	90	-	Cairns et al. 1978
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 10 <sup>o</sup> C)	70	-	Cairns et al. 1978
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 15 <sup>o</sup> C)	40	-	Cairns et al. 1978
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility; 25 <sup>o</sup> C)	7	-	Cairns et al. 1978
Cladoceran (4 days), <i>Daphnia magna</i>	S,U	Copper sulfate	-	24 hr	EC50 (filtration rate)	59	-	Ferrando and Andreu 1993
Cladoceran (24-48 hr), <i>Daphnia magna</i>	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	380	-	Ferrando et al. 1992
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	50		EC50	7		Oikari et al. 1992
Cladoceran, <i>Daphnia magna</i>	S,U	Copper sulfate	-	48 hr	EC50 (mobility)	45	-	Oikari et al. 1992
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,U	Copper sulfate	145	Life span (ca. 18 wk)	Chronic limits (inst. rate of population growth)	70	-	Winner and Farrell 1976
Cladoceran (<24 hrs), <i>Daphnia magna</i>	S,M,D	Copper sulfate	72-80	48 hr	LC50	-	11.3	Suedel et al. 1996
Cladoceran (<24 hrs), <i>Daphnia magna</i>	S,M,I	-	180	-	LC50	55.3	-	Borgmann and Charlton 1984
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	46.0	-	Meador 1991
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	57.2	-	Meador 1991

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,I	Copper sulfate	100	48 hr	EC50 (mobility)	67.8	-	Meador 1991
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	52.8	-	Winner 1984b
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,T	Copper sulfate	100	72 hr	EC50 (mobility)	56.3	-	Winner 1984b
Cladoceran (<24 hr), <i>Daphnia magna</i>	S,M,T	Copper chloride	85	96 hr	EC50 (mobility)	130	-	Blaylock et al. 1985
Cladoceran (24 hr), <i>Daphnia magna</i>	R,U	Copper sulfate	-	48 hr	EC50 (mobility)	18	-	Kazlauskiene et al. 1994
Cladoceran (<24 hr), <i>Daphnia parvula</i>	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	72	-	Winner and Farrell 1976
Cladoceran (<24 hr), <i>Daphnia parvula</i>	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	57	-	Winner and Farrell 1976
Cladoceran (<24 hr), <i>Daphnia parvula</i>	S,U	Copper sulfate	145	Life span (ca. 10 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, <i>Daphnia pulex</i>	S,U	Copper sulfate	45		EC50	10		Cairns et al. 1978
Cladoceran, <i>Daphnia pulex</i>	S,U	-	45		EC50	53		Mount and Norberg 1984
Cladoceran (<24 hrs), <i>Daphnia pulex</i>	S, U	Copper chloride	240		EC50	31		Elnabarawy et al. 1986
Cladoceran (<24 hrs), <i>Daphnia pulex</i>	S, U	Copper sulfate	33.8		EC50	3.6		Koivisto et al. 1992
Cladoceran (<24 hrs), <i>Daphnia pulex</i>	S,U	Copper chloride	80-90		EC50	18		Roux et al. 1993
Cladoceran (<24 hrs), <i>Daphnia pulex</i>	S,U	Copper chloride	80-90		EC50	24		Roux et al. 1993
Cladoceran (<24 hrs), <i>Daphnia pulex</i>	S,U	Copper chloride	80-90		EC50	22		Roux et al. 1993
Cladoceran (<24 hr), <i>Daphnia pulex</i>	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	86	-	Winner and Farrell 1976
Cladoceran (<24 hr), <i>Daphnia pulex</i>	S,U	Copper sulfate	145	72 hr	EC50 (mobility)	54	-	Winner and Farrell 1976
Cladoceran (<24 hr), <i>Daphnia pulex</i>	S,U	Copper sulfate	145	Life span (ca. 7 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, <i>Daphnia pulex</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	70	-	Cairns et al. 1978
Cladoceran, <i>Daphnia pulex</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	60	-	Cairns et al. 1978
Cladoceran, <i>Daphnia pulex</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	20	-	Cairns et al. 1978
Cladoceran, <i>Daphnia pulex</i>	S,U	Copper sulfate	45	48 hr	EC50 (mobility)	56	-	Cairns et al. 1978

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr), <i>Daphnia pulex</i>	S,U	Copper sulfate	200	24 hr	EC50 (mobility)	37.5	-	Lilius et al. 1995
Cladoceran, <i>Daphnia pulex</i>	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	29	-	Ingersoll and Winner 1982
Cladoceran, <i>Daphnia pulex</i>	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	20	-	Ingersoll and Winner 1982
Cladoceran, <i>Daphnia pulex</i>	S,M,T	Copper sulfate	106	48 hr	EC50 (mobility)	25	-	Ingersoll and Winner 1982
Cladoceran, <i>Daphnia pulex</i>	R,U	Copper sulfate	85	21 days	Reduced fecundity	3	-	Roux et al. 1993
Cladoceran, <i>Daphnia pulex</i>	R,M,T	Copper sulfate	106	70 days	Significantly shortened life span; reduced brood size	20	-	Ingersoll and Winner 1982
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	31	48 hr	EC50 (mobility; TOC=14 mg/L)	55.4	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	29	49 hr	EC50 (mobility; TOC=13 mg/L)	55.3	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	28	50 hr	EC50 (mobility; TOC=13 mg/L)	53.3	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	28	50 hr	EC50 (mobility; TOC=28 mg/L)	97.2	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	100	51 hr	EC50 (mobility; TOC=34 mg/L)	199	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	86	52 hr	EC50 (mobility; TOC=34 mg/L)	627	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	84	53 hr	EC50 (mobility; TOC=32 mg/L)	165	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	16	54 hr	EC50 (mobility; TOC=12 mg/L)	35.5	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	151	55 hr	EC50 (mobility; TOC=13 mg/L)	78.8	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	96	56 hr	EC50 (mobility; TOC=28 mg/L)	113	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	26	57 hr	EC50 (mobility; TOC=25 mg/L)	76.4	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	84	58 hr	EC50 (mobility; TOC=13 mg/L)	84.7	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	92	59 hr	EC50 (mobility; TOC=21 mg/L)	184	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	-	106	60 hr	EC50 (mobility; TOC=34 mg/L)	240	-	Lind et al. manuscript
Cladoceran, <i>Daphnia pulicaria</i>	S,M,T	Copper sulfate	106	48 hr	LC50	240	-	Lind et al. manuscript
Cladoceran, <i>Simocephalus serrulatus</i>	S,M,T	Copper nitrate	8	24 hr	EC50 (mobility; TOC=11 mg/L)	12	-	Giesy et al. 1983

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran, <i>Simocephalus serrulatus</i>	S,M,T	Copper nitrate	16	25 hr	EC50 (mobility; TOC=12.4 mg/L)	7.2	-	Giesy et al. 1983
Cladoceran, <i>Simocephalus serrulatus</i>	S,M,T	Copper nitrate	16	26 hr	EC50 (mobility; TOC=15.6 mg/L)	24.5	-	Giesy et al. 1983
Cladoceran (<24 hr), <i>Simocephalus vetulus</i>	S,U	-	45			57		Mount and Norberg 1984
Cladoceran (life cycle), <i>Bosmina longirostris</i>	R,U	Copper sulfate	-	13 days	LOEC (intrinsic rate of population increase)	18	-	Koivisto and Ketola 1995
Copepods (mixed sp), Primarily <i>Acanthocyclops vernalis</i> and <i>Diacyclops thomasi</i>	R,M,I	Copper chloride	-	1 wk	EC20 (growth)	42	-	Borgmann and Ralph 1984
Copepod (adults and copepodids V), <i>Tropocyclops prasinus mexicanus</i>	S, U	Copper sulfate	10			29		Lalande and Pinel-Alloul 1986
Copepod (adults and copepodids V), <i>Tropocyclops prasinus mexicanus</i>	S, U	Copper sulfate	10	96 hr	LC50	247	-	Lalande and Pinel-Alloul 1986
Amphipod (0.4 cm), <i>Crangonyx pseudogracilis</i>	R,U	Copper sulfate	45-55			1290		Martin and Holdich 1986
Amphipod (4 mm), <i>Crangonyx psuedogracilis</i>	R,U	Copper sulfate	50	48 hr	LC50	2,440	-	Martin and Holdich 1986
Amphipod, <i>Gammarus fasciatus</i>	S,U	Copper sulfate	206	48 hr	LC50	210	-	Judy 1979
Amphipod, <i>Gammarus lacustris</i>	S,U	Copper sulfate	-	96 hr	LC50	1,500	-	Nebeker and Gaufin 1964
Amphipod (2-3 wk), <i>Hyallela azteca</i>	S,M,T	Copper sulfate	6-10	-	LC50	65.6	-	Suedel et al. 1996
Amphipod (0-1 wk), <i>Hyallela azteca</i>	R,M,T	Copper nitrate	130	10 wk	Significant mortality	25.4	-	Borgmann et al. 1993
Amphipod (7-14 days), <i>Hyallela azteca</i>	F,M,T	Copper sulfate	46	10 days	LC50	31	-	West et al. 1993
Crayfish (intermoult adult, 19.6 g), <i>Cambarus robustus</i>	S,M,D	-	10-12	96 hr	LC50	-	830	Taylor et al. 1995
Crayfish (1.9-3.2 cm), <i>Orconectes limosus</i>	S,M,T	Copper chloride	-	96 hr	LC50	600	-	Boutet and Chaisemartin 1973
Crayfish (3.0-3.5 cm), <i>Orconectes rusticus</i>	F,U	Copper sulfate	100-125			3,000		Hubschman 1967
Crayfish (embryo), <i>Orconectes rusticus</i>	F,U	Copper sulfate	113	2 wk	52% mortality of newly hatched young	250	-	Hubschman 1967

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Crayfish (3.14 mg dry wt.), <i>Orconectes rusticus</i>	F,U	Copper sulfate	113	2 wk	23% reduction in growth	15	-	Hubschman 1967
Crayfish (30-40 mm), <i>Orconectes</i> sp.		-	113	48 hr	LC50	2,370	-	Dobbs et al. 1994
Crayfish, <i>Procambarus clarkii</i>	F,M,T	Copper chloride	17	1358 hr	LC50	657	-	Rice and Harrison 1983
Mayfly (6th-8th instar), <i>Stenonema</i> sp.	S,M,T	-	110	48 hr	LC50	453	-	Dobbs et al. 1994
Mayfly, <i>Cloeon dipterium</i>	-	Copper sulfate	-	72 hr	LC50 (10 <sup>0</sup> C)	193	-	Braginskij and Shcherban 1978
Mayfly, <i>Cloeon dipterium</i>	-	-	-	72 hr	LC50 (15 <sup>0</sup> C)	95.2	-	Braginskij and Shcherban 1978
Mayfly, <i>Cloeon dipterium</i>	-	-	-	72 hr	LC50 (25 <sup>0</sup> C)	53	-	Braginskij and Shcherban 1978
Mayfly, <i>Cloeon dipterium</i>	-	-	-	72 hr	LC50 (30 <sup>0</sup> C)	4.8	-	Braginskij and Shcherban 1978
Mayfly, <i>Ephemerella grandis</i>	F,M,T	Copper sulfate	50	14 days	LC50	180-200	-	Nehring 1976
Mayfly, <i>Ephemerella subvaria</i>	S,M	Copper sulfate	44	48 hr	LC50	320	-	Warnick and Bell 1969
Mayfly (6th-8th instar), <i>Isonychia bicolor</i>	S,M,T	-	110	48 hr	LC50	223	-	Dobbs et al. 1994
Stonefly, <i>Pteronarcys californica</i>	F,M,T	Copper sulfate	50	14 days	LC50	12,000	-	Nehring 1976
Caddisfly, <i>Hydropsyche betteni</i>	S,M,T	Copper sulfate	44	14 days	LC50	32,000	-	Warnick and Bell 1969
Midge (2nd instar), <i>Chironomus riparius</i>	S,M,T	-	110	48 hr	LC50	1,170	-	Dobbs et al. 1994
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	42.7			16.7		Gauss et al. 1985
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	109.6			36.5		Gauss et al. 1985
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	172.3			98.2		Gauss et al. 1985
Midge (4th instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	42.7			211		Gauss et al. 1985
Midge (4th instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	109.6			977		Gauss et al. 1985
Midge (4th instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	172.3			1184		Gauss et al. 1985
Midge, <i>Chironomus tentans</i>	S,U	Copper sulfate	25			327		Khargarot and Ray 1989
Midge (2nd instar), <i>Chironomus tentans</i>	S,M,T	Copper sulfate	8	96 hr	LC50	630	-	Suedel et al. 1996

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Midge (4th instar), <i>Chironomus tentans</i>	F,M,T	Copper chloride	36	20 days	LC50	77.5	-	Nebeker et al. 1984b
Midge (embryo), <i>Tanytarsus dissimilis</i>	S,M,T	Copper chloride	46.8	10 days	LC50	16.3	-	Anderson et al. 1980
Midge, Unidentified	F,M,T,D	Copper sulfate	200	32 wk	Emergence	30	-	Hedtke 1984
Bryozoan (2-3 day ancestrula), <i>Lophopodella carteri</i>	S,U	-	190-220			510		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), <i>Pectinatella magnifica</i>	S,U	-	190-220			140		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), <i>Plumatella emarginata</i>	S,U	-	190-220			140		Pardue and Wood 1980
American eel (5.5 cm glass eel stage), <i>Anguilla rostrata</i>	S,U	Copper sulfate	40-48	96 hr	LC50	2,540		Hinton and Eversole 1978
American eel (9.7 cm black eel stage), <i>Anguilla rostrata</i>	S,U	Copper sulfate	40-48	96 hr	LC50	3,200		Hinton and Eversole 1979
American eel, <i>Anguilla rostrata</i>	S,M,T	Copper nitrate	53	96 hr	LC50	6,400	-	Rehboldt et al. 1971
American eel, <i>Anguilla rostrata</i>	S,M,T	Copper nitrate	55	96 hr	LC50	6,000	-	Rehboldt et al. 1972
Arctic grayling (larva), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	67.5		Buhl and Hamilton 1990
Arctic grayling (larva), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Arctic grayling (larva), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	131		Buhl and Hamilton 1990
Arctic grayling (swim-up), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	9.6		Buhl and Hamilton 1990
Arctic grayling (0.20 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	2.7		Buhl and Hamilton 1990
Arctic grayling (0.34 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	2.58		Buhl and Hamilton 1990
Arctic grayling (0.81 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	49.3		Buhl and Hamilton 1990
Arctic grayling (0.85 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	30		Buhl and Hamilton 1990
Coho salmon (larva), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	41.3	96 hr	LC50	21		Buhl and Hamilton 1990
Coho salmon (larva), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	41.3	96 hr	LC50	19.3		Buhl and Hamilton 1990
Coho salmon (0.41 g juvenile), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	41.3	96 hr	LC50	15.1		Buhl and Hamilton 1990

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Coho salmon (0.47 g juvenile), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Coho salmon (0.87 g juvenile), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	41.3	96 hr	LC50	31.9		Buhl and Hamilton 1990
Coho salmon (10 cm), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	-	72 hr	LC50	280	-	Holland et al. 1960
Coho salmon (9.7 cm), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	-	72 hr	LC50	190	-	Holland et al. 1960
Coho salmon (9.7 cm), <i>Oncorhynchus kisutch</i>	S,U	Copper sulfate	-	72 hr	LC50	480	-	Holland et al. 1960
Coho salmon (juvenile), <i>Oncorhynchus kisutch</i>	R,M,T,I	-	33	96 hr	LC50 (TOC=7.3 mg/L)	164	-	Buckley 1983
Coho salmon (juvenile), <i>Oncorhynchus kisutch</i>	R,M,T,I	-	33	96 hr	LC50	286		Buckley 1983
Coho salmon (6.3 cm), <i>Oncorhynchus kisutch</i>	F,U	Copper sulfate	-	30 days	LC50	360	-	Holland et al. 1960
Coho salmon (6.3 cm), <i>Oncorhynchus kisutch</i>	F,U	Copper sulfate	-	72 hr	LC50	370	-	Holland et al. 1960
Coho salmon (smolts), <i>Oncorhynchus kisutch</i>	F,M,T	Copper chloride	91	144 hr	Decrease in survival upon transfer to 30 ppt seawater	20	-	Lorz and McPherson 1976
Coho salmon (smolts >10 cm), <i>Oncorhynchus kisutch</i>	F,M,T	Copper chloride	91	165 days	Decrease in downstream migration after release	5	-	Lorz and McPherson 1976
Coho salmon (7.8 cm), <i>Oncorhynchus kisutch</i>	F,M,T	Copper acetate	276	14 wk	15% reduction in growth	70	-	Buckley et al. 1982
Coho salmon (7.8 cm), <i>Oncorhynchus kisutch</i>	-	-	276	7 days	LC50	220	-	Buckley et al. 1982
Coho salmon (3-8 g), <i>Oncorhynchus kisutch</i>	F,M,T	Copper acetate	280	7 days	LC50	275	-	McCarter and Roch 1983
Coho salmon (3-8 g), <i>Oncorhynchus kisutch</i>	F,M,T	Copper acetate	280	7 days	LC50 (acclimated to copper for 2 wk)	383	-	McCarter and Roch 1983
Coho salmon (parr), <i>Oncorhynchus kisutch</i>	F,M,T,D,I	-	24.4	61 days	NOEC (growth and survival)	22	-	Mudge et al. 1993
Coho salmon, <i>Oncorhynchus kisutch</i>	F,M,T,D,I	-	31.1	60 days	NOEC (growth and survival)	18	-	Mudge et al. 1993
Coho salmon (parr), <i>Oncorhynchus kisutch</i>	F,M,T,D,I	-	31	61 days	NOEC (growth and survival)	33	-	Mudge et al. 1993
Rainbow trout (15-40g) <i>Oncorhynchus mykiss</i>	F,M,	Copper chloride	--	120 hr	LA50 (50% mortality)	~1.4 µg Cu/g gill	-	MacRae et al. 1999
Sockeye salmon (yeasrling), <i>Oncorhynchus nerka</i>	S,U	Copper sulfate	12	1-24 hr	Drastic increase in plasma corticosteroids	64	-	Donaldson and Dye 1975
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	220	-	Davis and Shand 1978



**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	210	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	103	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Chinook salmon (18-21 weeks), <i>Oncorhynchus tshawytscha</i>	S,U	Copper sulfate	211	96 hr	LC50	58	-	Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), <i>Oncorhynchus tshawytscha</i>	S,U	Copper sulfate	211	96 hr	LC50	54	-	Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), <i>Oncorhynchus tshawytscha</i>	S,U	Copper sulfate	343	96 hr	LC50	60	-	Hamilton and Buhl 1990
Chinook salmon (5.2 cm), <i>Oncorhynchus tshawytscha</i>	S,U	Copper nitrate	-	5 days	LC50	178	-	Holland et al. 1960
Chinook salmon (eyed embryos) <i>Oncorhynchus tshawytscha</i>	F,M,D	Copper sulfate	44	26 days	93% mortality	41.67	-	Hazel and Meith 1970
Chinook salmon (alevin), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC50	20	-	Chapman 1978
Chinook salmon (alevin), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC10	15	-	Chapman 1978
Chinook salmon (swimup), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC50	19	-	Chapman 1978
Chinook salmon (swimup), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC10	14	-	Chapman 1978
Chinook salmon (parr), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC50	30	-	Chapman 1978
Chinook salmon (parr), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC10	17	-	Chapman 1978
Chinook salmon (smolt), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC50	26	-	Chapman 1978
Chinook salmon (smolt), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper chloride	23	200 hr	LC10	18	-	Chapman 1978
Chinook salmon (3.9-6.8 cm), <i>Oncorhynchus tshawytscha</i>	F,M,T	Copper sulfate	20-22	96 hr	LC50	32	-	Finlayson and Verrue 1982
Cutthroat trout (3-5 mo), <i>Oncorhynchus clarki</i>	F,M	Copper chloride	50	20 min	avoidance of copper	7.708	-	Woodward et al. 1997

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout, <i>Oncorhynchus mykiss</i>	-	-	320	48 hr	LC50	500	-	Brown 1968
Rainbow trout (9-16 cm), <i>Oncorhynchus mykiss</i>	In situ	-	21-26	48 hr	LC50	70	-	Calamari and Marchetti 1975
Rainbow trout (0.4 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50	185	-	Bills et al. 1981
Rainbow trout (larva), <i>Oncorhynchus mykiss</i>	S, U	Copper sulfate	41.3	96 hr	LC50	36	-	Buhl and Hamilton 1990
Rainbow trout (0.60 g juvenile), <i>Oncorhynchus mykiss</i>	S, U	Copper sulfate	41.3	96 hr	LC50	13.8	-	Buhl and Hamilton 1990
Rainbow trout (13-15 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	250	72 hr	LC50	580	-	Brown et al. 1974
Rainbow trout (13-15 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	250	72 hr	LC50	960	-	Brown et al. 1974
Rainbow trout (3.2 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	24 hr	LC50	140	-	Shaw and Brown 1974
Rainbow trout (3.2 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	24 hr	LC50	130	-	Shaw and Brown 1974
Rainbow trout (4.0-10.6 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>o</sup> C)	950	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>o</sup> C)	430	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>o</sup> C)	150	-	Cairns et al. 1978
Rainbow trout (0.52-1.55 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50 (Silver Cup diet)	23.9	-	Marking et al. 1984
Rainbow trout (0.41-2.03 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50 (purified H440)	11.3	-	Marking et al. 1984
Rainbow trout (0.0.40-1.68 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50 (SD-9 diet)	15.9	-	Marking et al. 1984
Rainbow trout (0.0.34-1.52 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50 (liver diet)	14.3	-	Marking et al. 1984
Rainbow trout (0.0.38-1.30 g), <i>Oncorhynchus mykiss</i>	S,U	Copper sulfate	-	96 hr	LC50 (brine shrimp diet)	11.3	-	Marking et al. 1984
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	S,U	Copper chloride	30	56 hr	LC50	100	-	Rombough 1985
Rainbow trout (6.6 cm), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	320	72 hr	LC50	1,100	-	Lloyd 1961
Rainbow trout (6.6 cm), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	17.5	7 days	LC50	44	-	Lloyd 1961
Rainbow trout, <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	320	48 hr	LC50	270	-	Herbert and Vandyke 1964
Rainbow trout (yearling), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	240	48 hr	LC50	750	-	Brown and Dalton 1970

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Rainbow trout (13-15 cm), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	250	8 days	LC50	500	-	Brown et al. 1974
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	104	28 days	LC50	90	-	Birge 1978; Birge et al. 1978
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	101	28 days	EC50 (death or deformity)	110	-	Birge et al. 1980; Birge and Black 1979
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	101	28 days	EC10 (death or deformity)	16.5	-	Birge et al. 1980
Rainbow trout (eyed embryos), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	-	96 hr	LC50	1,150	-	Kazlauskiene et al. 1994
Rainbow trout (larva), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	-	96 hr	LC50	430	-	Kazlauskiene et al. 1994
Rainbow trout (16-18 cm), <i>Oncorhynchus mykiss</i>	R,U	Copper sulfate	-	96 hr	LC50	930	-	Kazlauskiene et al. 1994
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	62.9	7-9 mo	Lesions in olfactory rosettes	22	-	Saucier et al. 1991b
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	62.9	7-9 mo	31% mortality	22	-	Saucier et al. 1991b
Rainbow trout (eyed embryos), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	40-48	96 hr	LC50	400	-	Giles and Klaverkamp 1982
Rainbow trout (yearling), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	36.5	21 days	Elevated plasma cortisol returned to normal	45	-	Munoz et al. 1991
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	44	96 hr	15-20% post-hatch mortality	80	-	Giles and Klaverkamp 1982
Rainbow trout (embryo), <i>Oncorhynchus mykiss</i>	R,M,T	Copper sulfate	62.9	7-9 mo	Inhibited olfactory discrimination	22	-	Saucier et al. 1991a
Rainbow trout (5.1-7.6 cm), <i>Oncorhynchus mykiss</i>	F,U	Copper nitrate	-	96 hr	LC50	253	-	Hale 1977
Rainbow trout (11 cm), <i>Oncorhynchus mykiss</i>	F,U	-	100	96 hr	LC50	250	-	Goettl et al. 1972
Rainbow trout (5 wk post swimup) <i>Oncorhynchus mykiss</i>	F,U	Copper sulfate	89.5	1 hr	Avoidance	10	-	Folmar 1976
Rainbow trout (18.5-26.5 cm), <i>Oncorhynchus mykiss</i>	F,U	Copper sulfate	90	2 hr	55% depressed olfactory response	50	-	Hara et al. 1976
Rainbow trout (3.2 cm), <i>Oncorhynchus mykiss</i>	F,M,I	Copper sulfate	-	8 days	LC50	500	-	Shaw and Brown 1974
Rainbow trout (12-16 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	300	14 days	LC50	870	-	Calamari and Marchetti 1973
Rainbow trout (adult), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	42	-	LC50	57	-	Chapman 1975, Chapman and Stevens 1978
Rainbow trout (53.5 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	365	96 hr	LC50	465	-	Lett et al. 1976

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Rainbow trout (53.5 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	365	15 days	Transient decrease in food consumption	100	-	Lett et al. 1976
Rainbow trout (alevin), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24	200 hr	LC50	20	-	Chapman 1978
Rainbow trout (alevin), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24	200 hr	LC10	19	-	Chapman 1978
Rainbow trout (swimup), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24	200 hr	LC50	17	-	Chapman 1978
Rainbow trout (swimup), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24	200 hr	LC10	9	-	Chapman 1978
Rainbow trout (parr), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	25	200 hr	LC50	15	-	Chapman 1978
Rainbow trout (parr), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	25	200 hr	LC10	8	-	Chapman 1978
Rainbow trout (smolt), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	25	200 hr	LC50	21	-	Chapman 1978
Rainbow trout (smolt), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	25	200 hr	LC10	7	-	Chapman 1978
Rainbow trout, <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	74	-	Black and Birge 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	49	15-18 days	LC50	48	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	51	15-18 days	LC50	46	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	57	15-18 days	LC50	63	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	12	15-18 days	LC50	19	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	99	15-18 days	LC50	54	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	98	15-18 days	LC50	78	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	12	15-18 days	LC50	18	-	Miller and MacKay 1980
Rainbow trout (>8 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	97	15-18 days	LC50	96	-	Miller and MacKay 1980
Rainbow trout (200-250 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	320	4 mo	Altered liver and blood enzymes and mitochondrial function	30	-	Arillo et al. 1984
Rainbow trout (7 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	28.4	20 min	Avoidance	6.4	-	Giattina et al. 1982
Rainbow trout (2.70 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	9.2	96 hr	LC50	4.2	-	Cusimano et al. 1986
Rainbow trout (2.88 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	9.2	96 hr	LC50	66	-	Cusimano et al. 1986

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (2.88 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	9.2	168 hr	LC50	36.7	-	Cusimano et al. 1986
Rainbow trout (2.70 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	9.2	168 hr	LC50	3.1	-	Cusimano et al. 1986
Rainbow trout (2.65 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	9.2	168 hr	LC50	2.3	-	Cusimano et al. 1986
Rainbow trout (5 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	8,000	-	Shazili and Pascoe 1986
Rainbow trout (10 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	2,000	-	Shazili and Pascoe 1986
Rainbow trout (15 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (22 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	600	-	Shazili and Pascoe 1986
Rainbow trout (29 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (36 day embryo), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (2 day larva), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (7 day larva), <i>Oncorhynchus mykiss</i>	F,M,T	Copper nitrate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (yearling), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	63	15 days	Olfactory receptor degeneration	20	-	Julliard et al. 1993
Rainbow trout (swimup), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	60.9	13-40 wk	Inhibited olfactory discrimination	20	-	Saucier and Astic 1995
Rainbow trout (swimup), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	60.9	40 wk	43% mortality	40	-	Saucier and Astic 1995
Rainbow trout (9.0-11.5 cm, 10.6 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	284	96 hr	LC50	650	-	Svecevicius and Vosyliene 1996
Rainbow trout (3.5 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24.2	96 hr	LC50	12.7	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24.2	96 hr	LC50	16.6	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24.2	96 hr	LC50	21.4	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), <i>Oncorhynchus mykiss</i>	F,M,T	Copper chloride	24.2	96 hr	LC50	34.2	-	Marr et al. Manuscript
Rainbow trout (10.0 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	362	144 hr	LC50 (extruded diet)	276	-	Dixon and Hilton 1981
Rainbow trout (10.9 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	362	144 hr	LC50 (steam pelleted diet)	350	-	Dixon and Hilton 1981

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (12.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	362	144 hr	LC50 (Low carbohydrate diet)	408	-	Dixon and Hilton 1981
Rainbow trout (11.6 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	362	144 hr	LC50 (high carbohydrate diet)	246	-	Dixon and Hilton 1981
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	329	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	333	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	311	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	274	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level	371	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 30 µg/L)	266	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 58 µg/L)	349	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 94 µg/L)	515	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 131 µg/L)	564	-	Dixon and Sprague 1981a
Rainbow trout (1.7-3.3 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper sulfate	374	21 days	Incipient lethal level (acclimated to 194 µg/L)	708	-	Dixon and Sprague 1981a
Rainbow trout (2.9 g), <i>Oncorhynchus mykiss</i>	F,M,D	Copper chloride	30.5	ca. 2 hr	Inhibited avoidance of serine	6.667	-	Rehnberg and Schreck 1986
Rainbow trout (3.2 g), <i>Oncorhynchus mykiss</i>	F,M,T,D	Copper sulfate	30	96 hr	LC50	-	19.9	Howarth and Sprague 1978
Rainbow trout (1.4 g), <i>Oncorhynchus mykiss</i>	F,M,T,D	Copper sulfate	101	96 hr	LC50	-	176	Howarth and Sprague 1978
Rainbow trout (2.2 g), <i>Oncorhynchus mykiss</i>	F,M,T,D	Copper sulfate	370	96 hr	LC50	-	232	Howarth and Sprague 1978
Rainbow trout (smolt), <i>Oncorhynchus mykiss</i>	F,M,T,D	Copper sulfate	363	>10 days	LC50	97.92	-	Fogels and Sprague 1977
Rainbow trout (parr), <i>Oncorhynchus mykiss</i>	F,M,T,D,I	-	31.0	62 days	NOEC (growth and survival)	90	-	Mudge et al. 1993
Atlantic salmon (2-3 yr parr), <i>Salmo salar</i>	S,M,T	-	8-10	96 hr	LC50	125	-	Wilson 1972
Atlantic salmon (6.4-11.7 cm), <i>Salmo salar</i>	F,M,T	Copper sulfate	20	7 days	LC50	48	-	Sprague 1964
Atlantic salmon (7.2-10.9 cm), <i>Salmo salar</i>	F,M,T	-	14	7 days	LC50	32	-	Sprague and Ramsay 1965
Brown trout (3-6 day larva), <i>Salmo trutta</i>	S,M,T	Copper chloride	4	30 days	>90% mortality	80	-	Reader et al. 1989

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

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Brown trout (larva), <i>Salmo trutta</i>	S,M,T	Copper chloride	4	30 days	>90% mortality	20	-	Sayer et al. 1989
Brown trout (larva), <i>Salmo trutta</i>	S,M,T	Copper chloride	22	30 days	<10% mortality	80	-	Sayer et al. 1989
Brown trout (larva), <i>Salmo trutta</i>	F,M,T	Copper chloride	25	60 days	Inhibited growth	4.6	-	Marr et al. 1996
Brook trout, <i>Salvelinus fontinalis</i>	-	-	-	24 hr	Significant change in cough rate	9	-	Drummond et al. 1973
Brook trout (1 g), <i>Salvelinus fontinalis</i>	S,M,T	Copper chloride	4	80 hr	75% mortality	25.4	-	Sayer et al. 1991 b, c
Brook trout (8 mo), <i>Salvelinus fontinalis</i>	R,M,T	-	20	10 days	IC50 (growth)	187	-	Jop et al. 1995
Brook trout (15-20 cm), <i>Salvelinus fontinalis</i>	F,M,T	Copper sulfate	47	21 days	Altered Blood Hct, RBC, Hb, Cl, PGOT, Osmolarity, protein	38.2	-	McKim et al. 1970
Brook trout (13-20 cm), <i>Salvelinus fontinalis</i>	F,M,T	Copper sulfate	47	337 days	Altered blood PGOT	17.4	-	McKim et al. 1970
Goldfish (3.8-6.3 cm), <i>Carassius auratus</i>	S,U	Copper sulfate	20	96 hr	LC50	36	-	Pickering and Henderson 1966
Goldfish (10.5 g), <i>Carassius auratus</i>	S,M,T	Copper sulfate	34.2	-	LC50	150	-	Hossain et al. 1995
Goldfish (embryo), <i>Carassius auratus</i>	R,U	Copper sulfate	195	7 days	EC50 (death or deformity)	5,200	-	Birge 1978; Birge and Black 1979
Goldfish, <i>Carassius auratus</i>	R,U	Copper sulfate	45	24 hr	LC50 (5 <sup>o</sup> C)	2,700	-	Cairns et al. 1978
Goldfish, <i>Carassius auratus</i>	R,U	Copper sulfate	45	24 hr	LC50 (15 <sup>o</sup> C)	2,900	-	Cairns et al. 1978
Goldfish, <i>Carassius auratus</i>	R,U	Copper sulfate	45	24 hr	LC50 (30 <sup>o</sup> C)	1,510	-	Cairns et al. 1978
Common carp (1.8-2.1 cm), <i>Cyprinus carpio</i>	S,U	Copper sulfate	144-188	96 hr	LC50	117.5	-	Deshmukh and Marathe 1980
Common carp (5.0-6.0 cm), <i>Cyprinus carpio</i>	S,U	Copper sulfate	144-188	96 hr	LC50	530	-	Deshmukh and Marathe 1980
Common carp (embryo), <i>Cyprinus carpio</i>	S,U	Copper sulfate	360	-	EC50 (hatch and deformity)	4,775	-	Kapur and Yadav 1982
Common carp (embryo), <i>Cyprinus carpio</i>	S,U	Copper acetate	274	96 hr	LC50	140	-	Kaur and Dhawan 1994
Common carp (larva), <i>Cyprinus carpio</i>	S,U	Copper acetate	274	96 hr	LC50	4	-	Kaur and Dhawan 1994
Common carp (fry), <i>Cyprinus carpio</i>	S,U	Copper acetate	274	96 hr	LC50	63	-	Kaur and Dhawan 1994
Common carp, <i>Cyprinus carpio</i>	S,M,T	Copper nitrate	53	-	LC50	110	-	Rehwoldt et al. 1971
Common carp, <i>Cyprinus carpio</i>	S,M,T	Copper nitrate	55	-	LC50	800	-	Rehwoldt et al. 1972

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Common carp (4.7-6.2 cm), <i>Cyprinus carpio</i>	R,U	Copper sulfate	19	96 hr	LC50	63		Khangarot et al. 1983
Common carp (embryo and larva), <i>Cyprinus carpio</i>	R,U	Copper sulfate	50	108 hr	77% deformed	10	-	Wani 1986
Common carp (3.5 cm), <i>Cyprinus carpio</i>	R,U	Copper sulfate	-	96 hr	LC50	300	-	Alam and Maughan 1992
Common carp (6.5 cm), <i>Cyprinus carpio</i>	R,U	Copper sulfate	-	96 hr	LC50	1,000	-	Alam and Maughan 1992
Common carp (embryo), <i>Cyprinus carpio</i>	R,M,T	Copper sulfate	50	72 hr	Prevented hatching	700	-	Hildebrand and Cushman 1978
Common carp (1 mo), <i>Cyprinus carpio</i>	R,M,T	Copper nitrate	84.8	1 wk	Raised critical D.O. and altered ammonia excretion	14.0	-	De Boeck et al. 1995a
Common carp (22.9 cm), <i>Cyprinus carpio</i>	F,M,T	Copper chloride	17	48 hr	LC50	170	-	Harrison and Rice 1981
Common carp (embryo and larva), <i>Cyprinus carpio</i>	F,M,T	Copper chloride	100	168 hr	55% mortality	19	-	Stouthart et al. 1996
Common carp (embryo and larva), <i>Cyprinus carpio</i>	F,M,T	Copper chloride	100	168 hr	18% mortality;	50.8	-	Stouthart et al. 1996
Bonytail (larva), <i>Gila elegans</i>	S, U	Copper sulfate	199	96 hr	LC50	364		Buhl and Hamilton 1996
Bonytail (100-110 days), <i>Gila elegans</i>	S, U	Copper sulfate	199	96 hr	LC50	231		Buhl and Hamilton 1996
Golden shiner (11-13 cm), <i>Notemigonus crysoleucas</i>	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Golden shiner, <i>Notemigonus crysoleucas</i>	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>o</sup> C)	330	-	Cairns et al. 1978
Golden shiner, <i>Notemigonus crysoleucas</i>	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>o</sup> C)	230	-	Cairns et al. 1978
Golden shiner, <i>Notemigonus crysoleucas</i>	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>o</sup> C)	270	-	Cairns et al. 1978
Golden shiner, <i>Notemigonus crysoleucas</i>	F,M,T	Copper chloride	72.2	15 min	EC50 (avoidance)	26	-	Hartwell et al. 1989
Striped shiner, <i>Notropis chrysocephalus</i>	F,M,T,D	Copper sulfate	318	96 hr	LC50	3,400	-	Geckler et al. 1976
Striped shiner (4.7 cm) <i>Notropis chrysocephalus</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50	4,000	-	Geckler et al. 1976
Striped shiner (5.0 cm) <i>Notropis chrysocephalus</i>	F,M,T,D	Copper sulfate	274	96 hr	LC50	5,000	-	Geckler et al. 1976
Striped shiner, <i>Notropis chrysocephalus</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50	8,400	-	Geckler et al. 1976



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Striped shiner, <i>Notropis chrysocephalus</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50	16,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	208	48 hr	LC50	290	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	132	48 hr	LC50	150	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	182	48 hr	LC50	200	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	233	48 hr	LC50	180	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	282	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	337	48 hr	LC50	260	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	322	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	322	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	322	48 hr	LC50	25,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	203	48 hr	LC50	160	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	203	48 hr	LC50	1,100	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,U	Copper sulfate	203	48 hr	LC50	2,900	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	320	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	324	48 hr	LC50	9,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	324	48 hr	LC50	4,700	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	320	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	318	48 hr	LC50	5,700	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	318	48 hr	LC50	10,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	314	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	318	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	324	48 hr	LC50	9,700	-	Geckler et al. 1976

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	339	48 hr	LC50	7,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	310	48 hr	LC50	12,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	310	48 hr	LC50	21,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	302	48 hr	LC50	19,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	296	48 hr	LC50	8,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	332	48 hr	LC50	11,000	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	340	48 hr	LC50	6,300	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	296	48 hr	LC50	1,500	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	306	48 hr	LC50	750	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	308	48 hr	LC50	2,500	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	304	48 hr	LC50	1,600	-	Geckler et al. 1976
Bluntnose minnow, <i>Pimephales notatus</i>	S,M,D	Copper sulfate	315	48 hr	LC50	4,000	-	Geckler et al. 1976
Bluntnose minnow (3.9 cm), <i>Pimephales notatus</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50	6,800	-	Geckler et al. 1976
Bluntnose minnow (5.3 cm), <i>Pimephales notatus</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50	13,000	-	Geckler et al. 1976
Fathead minnow (adult), <i>Pimephales promelas</i>	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983
Fathead minnow (adult), <i>Pimephales promelas</i>	S,U	Copper sulfate	103-104	96 hr	LC50	310		Birge et al. 1983
Fathead minnow (adult), <i>Pimephales promelas</i>	S,U	Copper sulfate	103-104	96 hr	LC50	120		Birge et al. 1983
Fathead minnow (adult), <i>Pimephales promelas</i>	S,U	Copper sulfate	103-104	96 hr	LC50	210		Birge et al. 1983; Benson and Birge 1985
Fathead minnow (adult), <i>Pimephales promelas</i>	S,U	Copper sulfate	254-271	96 hr	LC50	390		Birge et al. 1983; Benson and Birge 1985
Fathead minnow, <i>Pimephales promelas</i>	S,U	Copper sulfate	200	96 hr	LC50	430		Mount 1968
Fathead minnow, <i>Pimephales promelas</i>	S,U	Copper sulfate	31	96 hr	LC50	84		Mount and Stephan 1969
Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	20	96 hr	LC50	25		Pickering and Henderson 1966

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Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	20	96 hr	LC50	22		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	360	96 hr	LC50	1760		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), <i>Pimephales promelas</i>	S,U	Copper sulfate	360	96 hr	LC50	1140		Pickering and Henderson 1966
Fathead minnow, <i>Pimephales promelas</i>	S,U	Copper sulfate	20	96 hr	LC50	50		Tarzwel and Henderson 1960
Fathead minnow, <i>Pimephales promelas</i>	S,U	Copper sulfate	400	96 hr	LC50	1,400		Tarzwel and Henderson 1960
Fathead minnow (3.2-4.2 cm), <i>Pimephales promelas</i>	S,M	Copper acetate	44	96 hr	LC50	117	-	Curtis et al. 1979; Curtis and Ward 1981
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	294	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	120	96 hr	LC50	2,200	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	298	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	280	96 hr	LC50	3,300	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	244	96 hr	LC50	1,600	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	212	96 hr	LC50	2,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	260	96 hr	LC50	3,500	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	224	96 hr	LC50	9,700	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	228	96 hr	LC50	5,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	150	96 hr	LC50	2,800	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	310	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	280	96 hr	LC50	12,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	280	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	260	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	308	96 hr	LC50	4,670	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	206	96 hr	LC50	920	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	262	96 hr	LC50	1,190	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	322	96 hr	LC50	2,830	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	210	96 hr	LC50	1,450	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	260	96 hr	LC50	1,580	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	252	96 hr	LC50	1,000	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	312	96 hr	LC50	5,330	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	276	96 hr	LC50	4,160	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	252	96 hr	LC50	10,550	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	298	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	282	96 hr	LC50	21,800	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	284	96 hr	LC50	23,600	-	Geckler et al. 1976
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper nitrate	290	96 hr	LC50	>200	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	16.8	96 hr	LC50	36.0	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	70.3	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	85.6	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	182.0	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17	96 hr	LC50	1.99	-	Welsh et al. 1993

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	20.5	96 hr	LC50	4.86	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	16.5	96 hr	LC50	11.1	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17.5	96 hr	LC50	9.87	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17	96 hr	LC50	15.7	-	Welsh et al. 1993
Fathead minnow (60-90 days), <i>Pimephales promelas</i>	S,M,T	-	110	48 hr	LC50	284	-	Dobbs et al. 1994
Fathead minnow (3 wk), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	101	48 hr	Short-term intolerance of hypoxia (2 mg D.O./L)	186	-	Bennett et al. 1995
Fathead minnow (2-4 day), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	6-10	-	LC50	12.5	-	Suedel et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	9.9	96 hr	LC50	10.7	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	7.1	96 hr	LC50	6.3	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	8.3	96 hr	LC50	12.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	8.9	96 hr	LC50	9.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	16.8	96 hr	LC50	26.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	12.2	96 hr	LC50	21.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	9.4	96 hr	LC50	19.8	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	11.4	96 hr	LC50	31.9	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	10.9	96 hr	LC50	26.1	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	12.4	96 hr	LC50	26.0	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17.4	96 hr	LC50	169.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	46	96 hr	LC50	17.15	14.87	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	46	96 hr	LC50	21.59	18.72	Erickson et al. 1996a,b

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	47	96 hr	LC50	123.19	106.8	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	45	96 hr	LC50	42.56	36.89	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	46	96 hr	LC50	83.19	72.13	Erickson et al. 1996a,b
Fathead minnow, <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	100	96 hr	LC50 (fish from metal-contaminated pond)	360	-	Birge et al. 1983
Fathead minnow, <i>Pimephales promelas</i>	S,M,T,D	Copper sulfate	250	96 hr	LC50 (fish from metal-contaminated pond)	410	-	Birge et al. 1983
Fathead minnow (<24 hr), <i>Pimephales promelas</i>	R,U	-	45	7 days	LC50	70	-	Norberg and Mount 1985
Fathead minnow (<24 hr), <i>Pimephales promelas</i>	R,U	-	45	7 days	LOEC (growth)	26	-	Norberg and Mount 1985
Fathead minnow (<24 hr), <i>Pimephales promelas</i>	R,U	Copper sulfate	345	4 days	RNA threshold effect	130	-	Parrott and Sprague 1993
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	5 days	LC50	480	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	5 days	LC50	440	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	5 days	EC50 (malformation)	270	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	5 days	EC50 (malformation)	260	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	LC50	310	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	LC50	330	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	EC50 (malformation)	190	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	EC50 (malformation)	170	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	LOEC (length)	160	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	LOEC (length)	180	-	Fort et al. 1996
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T	Copper sulfate	180	7 days	LOEC (growth)	25	-	Pickering and Lazorchak 1995
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (3-7 days), <i>Pimephales promelas</i>	R,M,T	Copper sulfate	74	48 hr	LC50	225	-	Diamond et al. 1997b

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	35.9	-	Diamond et al. 1997a
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	28.9	-	Diamond et al. 1997a
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	20.7	-	Diamond et al. 1997a
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	80.8	-	Diamond et al. 1997a
Fathead minnow (3-7 days), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	297.1	-	Diamond et al. 1997b
Fathead minnow (3-7 days), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	72	48 hr	LC50	145.8	-	Diamond et al. 1997b
Fathead minnow (32-38 mm), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	244	9 mo	LOEC (93% lower fecundity)	120	-	Brungs et al. 1976
Fathead minnow (larva), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	202	-	LC50	250	-	Scudder et al. 1988
Fathead minnow (embryo), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	202	34 days	Reduced growth; increased abnormality	61	-	Scudder et al. 1988
Fathead minnow (embryo), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	202	34 days	LC50	123	-	Scudder et al. 1988
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	10.7	21 days	Incipient lethal level	6.2	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	10.7	21 days	Growth (length) reduced by 8%	5.3	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	9.3	21 days	Incipient lethal level	17.2	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	9.3	21 days	Growth (length) reduced by 17%	16.2	-	Welsh 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	46	96 hr	LC50	305	-	Erickson et al. 1996 a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	46	96 hr	LC50	298.6	-	Erickson et al. 1996 a, b
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	30	96 hr	LC50 (TOC=12 mg/L)	436	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	37	96 hr	LC50 (TOC=13 mg/L)	516	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	87	96 hr	LC50 (TOC=36 mg/L)	1,586	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	73	96 hr	LC50 (TOC=28 mg/L)	1,129	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	84	96 hr	LC50 (TOC=15 mg/L)	550	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	66	96 hr	LC50 (TOC=34 mg/L)	1,001	-	Lind et al. manuscript

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	117	96 hr	LC50 (TOC=30 mg/L)	2,050	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	121	96 hr	LC50 (TOC=30 mg/L)	2,336	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	Copper sulfate	117	96 hr	LC50	2,050	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	Copper sulfate	121	96 hr	LC50	2,336	-	Lind et al. manuscript
Fathead minnow (4.4 cm), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50	11,000	-	Geckler et al. 1976
Fathead minnow (4.2 cm), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50	15,000	-	Geckler et al. 1976
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	45	96 hr	LC50	158.8	138.1	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	45	96 hr	LC50	80.01	72.01	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	46	96 hr	LC50	20.96	18.23	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	44	96 hr	LC50	50.8	39.12	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T,D	Copper sulfate	45	96 hr	LC50	65.41	45.78	Erickson et al. 1996a,b
Colorado squawfish (larva), <i>Ptychocheilus lucius</i>	S,U	Copper sulfate	199	96 hr	LC50	363		Buhl and Hamilton 1996
Colorado squawfish (155-186 days), <i>Ptychocheilus lucius</i>	S,U	Copper sulfate	199	96 hr	LC50	663		Buhl and Hamilton 1996
Colorado squawfish (32-40 days posthatch), <i>Ptychocheilus lucius</i>	S,U	Copper sulfate	144	96 hr	LC50	293		Hamilton and Buhl 1997
Colorado squawfish (32-40 days posthatch), <i>Ptychocheilus lucius</i>	S,U	Copper sulfate	144	96 hr	LC50	320		Hamilton and Buhl 1997
Creek chub, <i>Semotilus atromaculatus</i>	F,M,T	Copper sulfate	316	96 hr	LC50	11,500	-	Geckler et al. 1976
Creek chub, <i>Semotilus atromaculatus</i>	F,M,T	Copper sulfate	274	96 hr	LC50	1,100	-	Geckler et al. 1976
Razorback sucker (larva), <i>Xyrauchen texanus</i>	S,U	Copper sulfate	199	96 hr	LC50	404		Buhl and Hamilton 1996
Razorback sucker (102-116 days), <i>Xyrauchen texanus</i>	S,U	Copper sulfate	199	96 hr	LC50	331		Buhl and Hamilton 1996
Razorback sucker (13-23 days posthatch), <i>Xyrauchen texanus</i>	S,U	Copper sulfate	144	96 hr	LC50	231		Hamilton and Buhl 1997



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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Razorback sucker (13-23 days posthatch), <i>Xyrauchen texanus</i>	S,U	Copper sulfate	144	96 hr	LC50	314		Hamilton and Buhl 1997
Brown bullhead, <i>Ictalurus nebulosus</i>	F,M,T	Copper sulfate	303	96 hr	LC50	12,000	-	Geckler et al. 1976
Brown bullhead (5.2 cm), <i>Ictalurus nebulosus</i>	F,M,T	Copper sulfate	314	96 hr	LC50	5,200	-	Geckler et al. 1976
Channel catfish (13-14 cm), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Channel catfish, <i>Ictalurus punctatus</i>	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>o</sup> C)	3,700	-	Cairns et al. 1978
Channel catfish, <i>Ictalurus punctatus</i>	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>o</sup> C)	2,600	-	Cairns et al. 1978
Channel catfish, <i>Ictalurus punctatus</i>	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>o</sup> C)	3,100	-	Cairns et al. 1978
Channel catfish, <i>Ictalurus punctatus</i>	S,U	Copper sulfate	100	10 days	EC50 (death and deformity)	6,620	-	Birge and Black 1979
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	16	96 hr	LC50	54		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	16	96 hr	LC50	55		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	83	96 hr	LC50	762		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	83	96 hr	LC50	700		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	161	96 hr	LC50	768		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	161	96 hr	LC50	1139		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	287	96 hr	LC50	1041		Straus and Tucker 1993
Channel catfish (fingerlings), <i>Ictalurus punctatus</i>	S,U	Copper sulfate	287	96 hr	LC50	925		Straus and Tucker 1993
Channel catfish (400-600 g), <i>Ictalurus punctatus</i>	F,M,T	Copper sulfate	-	10 wk	Significant mortality	354	-	Perkins et al. 1997
Channel catfish (4.1 gm), <i>Ictalurus punctatus</i>	F,M,T,D	Copper sulfate	319	14 days	LC50	1,229	-	Richey and Roseboom 1978
Channel catfish (5.7 gm), <i>Ictalurus punctatus</i>	F,M,T,D	Copper sulfate	315	14 days	LC50	1,073	-	Richey and Roseboom 1978
Banded killifish, <i>Fundulus diaphanus</i>	S,M,T	Copper nitrate	53	-		860	-	Rehboldt et al. 1971
Banded killifish, <i>Fundulus diaphanus</i>	S,M,T	Copper nitrate	55	-		840	-	Rehboldt et al. 1972

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Flagfish (0.1-0.3 g), <i>Jordanella floridae</i>	F,M,T,D	Copper sulfate	363	10 days	LC50	-	680	Fogels and Sprague 1977
Flagfish (0.1-0.3 g), <i>Jordanella floridae</i>	F,M,T,D	Copper sulfate	363	96 hr	LC50	-	1,270	Fogels and Sprague 1977
Mosquitofish (3.8-5.1 cm female), <i>Gambusia affinis</i>	S,U	Copper nitrate	27-41	96 hr	LC50	93		Joshi and Rege 1980
Mosquitofish (3.8-5.1 cm female), <i>Gambusia affinis</i>	S,U	Copper sulfate	27-41	96 hr	LC50	200		Joshi and Rege 1980
Mosquitofish (2.5 cm male), <i>Gambusia affinis</i>	S,U	-	50	96 hr	LC50	3,500		Kallanagoudar and Patil 1997
Mosquitofish (2.5 cm male), <i>Gambusia affinis</i>	S,U	-	150	96 hr	LC50	5,000		Kallanagoudar and Patil 1997
Mosquitofish (2.5 cm male), <i>Gambusia affinis</i>	S,U	-	300	96 hr	LC50	6,000		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), <i>Gambusia affinis</i>	S,U	-	50	96 hr	LC50	2,500		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), <i>Gambusia affinis</i>	S,U	-	150	96 hr	LC50	2,900		Kallanagoudar and Patil 1997
Mosquitofish (3.5 cm female), <i>Gambusia affinis</i>	S,U	-	300	96 hr	LC50	5,000		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), <i>Gambusia affinis</i>	S,U	-	50	96 hr	LC50	900		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), <i>Gambusia affinis</i>	S,U	-	150	96 hr	LC50	1,400		Kallanagoudar and Patil 1997
Mosquitofish (0.8 cm fry), <i>Gambusia affinis</i>	S,U	-	300	96 hr	LC50	2,000		Kallanagoudar and Patil 1997
Mosquito fish, <i>Gambusia affinis</i>	S,U	Copper sulfate	-	96 hr	LC50 (high turbidity)	75,000	-	Wallen et al. 1957
Mosquito fish, <i>Gambusia affinis</i>	R,M	Copper sulfate	45	48 hr	LC50	180	-	Chagnon and Guttman 1989
Guppy (1.5 cm), <i>Poecilia reticulata</i>	S,U	Copper sulfate	230	96 hr	LC50	1,230		Khengarot 1981
Guppy (1.62 cm), <i>Poecilia reticulata</i>	S,U	Copper sulfate	240	96 hr	LC50	764		Khengarot et al. 1981b
Guppy (1.9-2.5 cm), <i>Poecilia reticulata</i>	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966
Guppy (1.5 cm), <i>Poecilia reticulata</i>	R,U	Copper sulfate	260	96 hr	LC50	2,500		Khengarot et al. 1981a
Guppy (0.8-1.0 cm), <i>Poecilia reticulata</i>	R,U	Copper sulfate	144-188	96 hr	LC50	160		Deshmukh and Marathe 1980
Guppy (1.2-2.3 cm; female), <i>Poecilia reticulata</i>	R,U	Copper sulfate	144-188	96 hr	LC50	275		Deshmukh and Marathe 1980

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Guppy (2.3-2.8 cm; male), <i>Poecilia reticulata</i>	R,U	Copper sulfate	144-188	96 hr	LC50	210		Deshmukh and Marathe 1980
Guppy (340 mg; female), <i>Poecilia reticulata</i>	R,U	Copper sulfate	144-188	96 hr	LC50	480		Deshmukh and Marathe 1980
Guppy (1.5 cm), <i>Poecilia reticulata</i>	R,U	Copper sulfate	260	48 hr	LC50	2,500	-	Khargarot et al. 1981a
Guppy (1.5 cm), <i>Poecilia reticulata</i>	R, U	Copper sulfate	181	96 hr	LC50	986	-	Khargarot and Ray 1987b
Guppy (1 mo), <i>Poecilia reticulata</i>	F,U	Copper sulfate	76	24 hr	LC50	1,370	-	Minicucci 1971
Guppy (1 mo), <i>Poecilia reticulata</i>	F,U	Copper sulfate	76	24 hr	LC50	930	-	Minicucci 1971
Guppy (1 mo), <i>Poecilia reticulata</i>	F,U	Copper sulfate	76	24 hr	LC50	1,130	-	Minicucci 1971
White perch, <i>Morone americana</i>	S,M,T	Copper nitrate	53	-	LC50	6,200	-	Rehwoldt et al. 1971
White perch, <i>Morone americana</i>	S,M,T	Copper nitrate	55	-	LC50	6,400	-	Rehwoldt et al. 1972
Striped bass (larva), <i>Morone saxatilis</i>	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (larva), <i>Morone saxatilis</i>	S,U	Copper sulfate	34.6	96 hr	LC50	100		Hughes 1973
Striped bass (3.5-5.1 cm), <i>Morone saxatilis</i>	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (3.1-5.1 cm), <i>Morone saxatilis</i>	S,U	Copper sulfate	34.6	96 hr	LC50	150		Hughes 1973
Striped bass (35-80 day), <i>Morone saxatilis</i>	S,U	Copper sulfate	285	96 hr	LC50	270		Palawski et al. 1985
Striped bass (6 cm), <i>Morone saxatilis</i>	S,U	Copper sulfate	35	96 hr	LC50	620		Wellborn 1969
Striped bass, <i>Morone saxatilis</i>	S,M,T	Copper nitrate	53	96 hr	LC50	4,300	-	Rehwoldt et al. 1971
Striped bass, <i>Morone saxatilis</i>	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972
Rock bass, <i>Ambloplites rupestris</i>	F,M,T	-	24	96 hr	LC50 (high TOC)	1,432	-	Lind et al. manuscript
Pumpkinseed (1.2 g), <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	53	-	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed (1.2 g), <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	55	-	LC50	2,700	-	Rehwoldt et al. 1972
Pumpkinseed, <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	53	96 hr	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed, <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper chloride	43	96 hr	LC50	770		Academy of Natural Sciences 1960
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	43	96 hr	LC50	1,250		Academy of Natural Sciences 1960 Cairns and Scheier 1968; Patrick et
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>o</sup> C)	2,590	-	Cairns et al. 1978
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>o</sup> C)	2,500	-	Cairns et al. 1978
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>o</sup> C)	3,820	-	Cairns et al. 1978
Bluegill (3-4 cm), <i>Lepomis macrochirus</i>	S,U	-	119	8 days	33% reduction in locomotor activity	40	-	Ellgaard and Guillot 1988
Bluegill (4.2 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	52	96 hr	LC50	254		Inglis and Davis 1972
Bluegill (4.2 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	209	96 hr	LC50	437		Inglis and Davis 1972
Bluegill (4.2 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	365	96 hr	LC50	648		Inglis and Davis 1972
Bluegill (5-15 g), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	35	2-6 days	8% increase in oxygen consumption rates	300	-	O'Hara 1971
Bluegill (3.8-6.3 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	20	96 hr	LC50	660		Pickering and Henderson 1966
Bluegill (3.8-6.3 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	360	96 hr	LC50	10,200		Pickering and Henderson 1966
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	20	96 hr	LC50	200		Tarzwel and Henderson 1960
Bluegill, <i>Lepomis macrochirus</i>	S,U	Copper sulfate	400	96 hr	LC50	10,000		Tarzwel and Henderson 1960
Bluegill (5-11 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	46	48 hr	LC50	3,000	-	Turnbull et al. 1954
Bluegill (5-11 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	101.2	48 hr	LC50	7,000	-	Turnbull et al. 1954
Bluegill (0.51g), <i>Lepomis macrochirus</i>	S,M,T	-	110	48 hr	LC50	4,300	-	Dobbs et al. 1994

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bluegill (5-9 cm), <i>Lepomis macrochirus</i>	S,M,T	Copper chloride	45-47	-	LC50	710	-	Trama 1954
Bluegill (5-9 cm), <i>Lepomis macrochirus</i>	S,M,T	Copper sulfate	45-47	-	LC50	770	-	Trama 1954
Bluegill (5-15 g), <i>Lepomis macrochirus</i>	F,M	Copper sulfate	35	-	LC50	2400	-	O'Hara 1971
Bluegill (3.5-6.0 cm), <i>Lepomis macrochirus</i>	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	8,480	-	Black and Birge 1980
Bluegill (3.2-6.7 cm), <i>Lepomis macrochirus</i>	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	1,100	-	Thompson et al. 1980
Bluegill (3.2-6.7 cm), <i>Lepomis macrochirus</i>	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	900	-	Thompson et al. 1980
Bluegill (35.6-62.3 g), <i>Lepomis macrochirus</i>	F,M,T	Copper sulfate	273.3	24-96 hr	Various behavioral changes	34	-	Henry and Atchison 1986
Bluegill, <i>Lepomis macrochirus</i>	F,M,T	Copper chloride	157	24-96 hr	27% reduction in food consumption	31	-	Sandheinrich and Atchison 1989
Bluegill, <i>Lepomis macrochirus</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	16,000	-	Geckler et al. 1976
Bluegill, <i>Lepomis macrochirus</i>	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	17,000	-	Geckler et al. 1976
Bluegill (0.14-0.93 g), <i>Lepomis macrochirus</i>	F,M,T,D	Copper sulfate	246	14 days	LC50	-	2,500	Richey and Roseboom 1978
Bluegill (1.15-2.42 g), <i>Lepomis macrochirus</i>	F,M,T,D	Copper sulfate	237	14 days	LC50	-	3,700	Richey and Roseboom 1978
Bluegill (48.3 g), <i>Lepomis macrochirus</i>	F,M,T,D	Copper sulfate	40	96 hr	Biochemical changes	2,000	-	Heath 1984
Largemouth bass (embryo), <i>Micropterus salmoides</i>	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	6,560	-	Birge et al. 1978; Birge and Black 1979
Largemouth bass, <i>Micropterus salmoides</i>	F,U	-	-	24 hr	Affected opercular rhythm	48	-	Morgan 1979
Rainbow darter, <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	4,500	-	Geckler et al. 1976
Rainbow darter, <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	8,000	-	Geckler et al. 1976
Rainbow darter, <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	274	96 hr	LC50 (high BOD)	2,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	4,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	5,300	-	Geckler et al. 1976
Fantail, <i>Etheostoma flabellare</i>	S,M,T	Copper sulfate	170	96 hr	Lowered critical thermal maximum	43	-	Lydy and Wissing 1988

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Johnny darter, <i>Etheostoma nigrum</i>	S,M,T	Copper sulfate	170	96 hr	Lowered critical thermal maximum	148	-	Lydy and Wissing 1988
Johnny darter, <i>Etheostoma nigrum</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	6,800	-	Geckler et al. 1976
Orangethroat darter, <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	7,100	-	Geckler et al. 1976
Orangethroat darter, <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	9,800	-	Geckler et al. 1976
Orangethroat darter, <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	7,900	-	Geckler et al. 1976
Orangethroat darter, <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	5,500	-	Geckler et al. 1976
Orangethroat darter, <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	274	96 hr	LC50 (high BOD)	5,800	-	Geckler et al. 1976
Orangethroat darter (4.4 cm), <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	7,100	-	Geckler et al. 1976
Orangethroat darter (4.4 cm), <i>Etheostoma spectabile</i>	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	9,400	-	Geckler et al. 1976
Mozambique tilapia (8.7 cm), <i>Tilapia mossambica</i>	S,U	Copper sulfate	115	96 hr	LC50	1,500	-	Qureshi and Saksema 1980
Leopard frog (embryo), <i>Rana pipiens</i>	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	50	-	Birge and Black 1979
Wood frog (larva), <i>Rana sylvatica</i>	S,U	Copper chloride	6.2	28 days	100% mortality	15	-	Horne and Dunson 1995
Wood frog (larva), <i>Rana sylvatica</i>	S,U	Copper chloride	12.4	28 days	Little effect	15	-	Horne and Dunson 1995
Wood frog (larva), <i>Rana sylvatica</i>	S,U	Copper chloride	6.2	28 days	Little effect	15	-	Horne and Dunson 1995
Wood frog (larva), <i>Rana sylvatica</i>	S,U	Copper chloride	12.4	28 days	Little effect	15	-	Horne and Dunson 1995
Narrow-mouthed toad (embryo), <i>Gastrophryne carolinensis</i>	R,U	Copper sulfate	195	7 days	EC50 (death and deformity)	40	-	Birge 1978; Birge and Black 1979
American toad, <i>Bufo americanus</i>	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	100	-	Black and Birge 1980
Fowler's toad (embryo), <i>Bufo fowleri</i>	R,U	Copper sulfate	195	7 days	LC50	40	-	Birge and Black 1979
Fowler's toad (embryo), <i>Bufo fowleri</i>	R,U	Copper sulfate	195	7 min	EC50 (death and deformity)	26,960	-	Birge and Black 1979
Southern gray treefrog (embryo), <i>Hyla chrysoscelis</i>	R,U	Copper sulfate	195	7 min	EC50 (death and deformity)	40	-	Birge and Black 1979
Marbled salamander (embryo), <i>Ambystoma opacum</i>	R,U	Copper sulfate	195	8 days	EC50 (death and deformity)	770	-	Birge et al. 1978; Birge and Black 1979
Jefferson salamander (larva), <i>Ambystoma jeffersonianum</i>	S,U	Copper chloride	6.2	7 days	LC100	15	-	Horne and Dunson 1995

**Appendix C1. Other Data on Effects of Copper on Freshwater Organisms**

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Jefferson salamander (larva), <i>Ambystoma jeffersonianum</i>	S,U	Copper chloride	12.4	28 days	LC100	15	-	Horne and Dunson 1995
Jefferson salamander (embryo), <i>Ambystoma jeffersonianum</i>	S,M,D	Copper chloride	6.5	96 hr	LC50	328.1	-	Horne and Dunson 1994
Two-lined Salamander, <i>Eurycea bislineata</i>	S,M,T	-	100-120	48 hr	LC50	1,120	-	Dobbs et al. 1994

a S = static; R = renewal; F = flow-through; M = measured; U = unmeasured; T = total metal concentration measured; D = dissolved metal concentration; I = ionic

b Results are expressed as copper, not as the chemical

c In river water

**Appendix C2. Other Data on Effects of Copper on Saltwater Organisms**

Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Natural phytoplankton populations	-	-	-	5 days	Reduced chlorophyll a	19	-	Hollibaugh et al. 1980
Natural phytoplankton populations	-	-	-	4 days	Reduced biomass	6.4	-	Hollibaugh et al. 1980
Dinoflagellate, <i>Glenodinium halli</i>	S,U	-	28	48 hr	No growth	10-160	-	Wilson and Freeberg 1980
Dinoflagellate, <i>Glenodinium halli</i>	S,U	-	28	48 hr	No effect on growth	2-120	-	Wilson and Freeberg 1980
Dinoflagellate, <i>Gymnodinium splendens</i>	S,U	-	28	48 hr	No growth	10-100	-	Wilson and Freeberg 1980
Dinoflagellate, <i>Gymnodinium splendens</i>	S,U	-	28	48 hr	No effect on growth	5-90	-	Wilson and Freeberg 1980
Phytoflagellate, <i>Isochrysis galbana</i>	S,U	-	28	48 hr	No growth	100-1,000	-	Wilson and Freeberg 1980
Phytoflagellate, <i>Isochrysis galbana</i>	S,U	-	28	48 hr	No effect on growth	20-300	-	Wilson and Freeberg 1980
Alga, <i>Laminaria hyperborica</i>	-	-	-	28 days	Growth decrease	50	-	Hopkins and Kain 1971
Diatom, <i>Asterionella japonica</i>	S,U	Copper sulfate	-	72 hr	EC50 (growth)	12.7	-	Fisher and Jones 1981
Diatom, <i>Thalassiosira pseudonana</i>	S,U	Copper chloride	30-34	72 hr	EC50 (growth rate)	6	-	Erickson 1972
Diatom, <i>Thalassiosira pseudonana</i>	S,U	-	28	48 hr	No growth	80-500	-	Wilson and Freeberg 1980
Diatom, <i>Thalassiosira pseudonana</i>	S,U	-	28	48 hr	No effect on growth	50-70	-	Wilson and Freeberg 1980
Red alga (gametophytes), <i>Ceramium strictum</i>	S,U	-	34	24 hr	EC50 (fertilization)	10-15	-	Eklund 1993
Red alga (mature), <i>Champia parvula</i>	S,U	-	30	48 hr	LOEC (reproduction)	2.0	-	U.S. EPA 1988
Red alga (mature), <i>Champia parvula</i>	S,U	Copper sulfate	30	48 hr	IC50 (fertilization)	1.4	-	Morrison et al. 1989
Red alga (female), <i>Chondrus crispus</i>		Copper sulfate	-	24 hr	14% reduction in growth	10	-	Staples et al. 1995
Bladderwrack (zygotes), <i>Fucus vesiculosus</i>	S,U	-	6	24 hr	EC50 (germination)	60	-	Andersson and Kautsky 1996
Kelp (mature sporophyte), <i>Laminaria saccharina</i>	S,U	Copper sulfate	-	1 hr	LOEC (28% decrease in meiospore release)	50	-	Chung and Brinkhuis 1986
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	99.1	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	19.4	-	Anderson et al. 1990



**Appendix C2. Other Data on Effects of Copper on Saltwater Organisms**

Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	54.1	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	55.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	94.5	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	50.1	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<40.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<31.1	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	<10.1	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	18.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	8.8	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	9.3	-	Anderson et al. 1990
Giant kelp (spores), <i>Macrocystis pyrifera</i>	S,M,T	Copper chloride	33	48 hr	NOEC (Germination)	10.2	-	Anderson et al. 1990
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	NOEC (Spore germination)	20	-	Garman et al. 1994
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	LOEC (Spore germination)	40	-	Garman et al. 1994
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	NOEC (Germ tube growth)	20	-	Garman et al. 1994
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	NOEC (Germ tube growth)	40	-	Garman et al. 1994
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	NOEC (Nuclear migration)	10	-	Garman et al. 1994
Giant kelp, <i>Macrocystis pyrifera</i>	R,M,T	Copper chloride	33-35	42 hr	NOEC (Nuclear migration)	20	-	Garman et al. 1994
Hydroid, <i>Campanularia flexuosa</i>	S,U	Copper chloride	FSW	11 days	Threshold reduced growth rate	13	-	Stebbing 1976
Hydroid, <i>Campanularia flexuosa</i>	S,U	Copper chloride	FSW	11 days	Glucosamidase increased	1.43	-	Moore and Stebbing 1976
Hydromedusa, <i>Phialidium</i> sp.	S,U	-	-	24 hr	LC50	36	-	Reeve et al. 1976
Ctenophore, <i>Pleurobrachia plicatilis</i>	S,U	-	-	24 hr	LC50	33	-	Reeve et al. 1976

**Appendix C2. Other Data on Effects of Copper on Saltwater Organisms**

Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Ctenophore, <i>Mnemiopsis mcradyi</i>	S,U	-	-	24 hr	LC50	17-29	-	Reeve et al. 1976
Rotifer, <i>Brachionus plicatilis</i>	S,U	-	-	24 hr	LC50	100	-	Reeve et al. 1976
Rotifer (<3 hr), <i>Brachionus plicatilis</i>	S, U	Copper sulfate	15	24 hr	LC50	120	-	Snell and Persoone 1989a
Rotifer (<3 hr), <i>Brachionus plicatilis</i>	S, U	Copper sulfate	30	24 hr	LC50	130	-	Snell and Persoone 1989a
Rotifer (<3 hr), <i>Brachionus plicatilis</i>	S,U	-	15	24 hr	LC50	63	-	Snell et al. 1991a
Rotifer (<3 hr), <i>Brachionus plicatilis</i>	S,U	-	15	24 hr	LC50	35	-	Snell et al. 1991a
Rotifer (<3 hr), <i>Brachionus plicatilis</i>	S,U	-	15	24 hr	LC50	170	-	Snell et al. 1991a
Rotifer (<5 hr), <i>Brachionus plicatilis</i>	S,U	Copper chloride	15	1 hr	NOEC (ingestion)	100	-	Juchelka and Snell 1995
Polychaete worm (embryos), <i>Hediste diversicolor</i>	R,U	Copper nitrate	14.6	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm (embryos), <i>Hediste diversicolor</i>	R,U	Copper nitrate	21.9	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm (embryos), <i>Hediste diversicolor</i>	R,U	Copper nitrate	29.2	6 days	Severe reduction in hatching	100	-	Ozoh and Jones 1990a
Polychaete worm, <i>Phyllodoce maculata</i>	R,U	Copper sulfate	-	9 days	LC50	80	-	McLusky and Phillips 1975
Polychaete worm, <i>Neanthes arenaceodentata</i>	F,M,T	Copper nitrate	31	28 days	LC50	44	-	Pesch and Morgan 1978
Polychaete worm, <i>Neanthes arenaceodentata</i>	F,M,T	Copper nitrate	31	28 days	LC50	100	-	Pesch and Morgan 1978
Polychaete worm, <i>Neanthes arenaceodentata</i>	F,M,T	Copper nitrate	31	7 days	LC50	137	-	Pesch and Hoffman 1982
Polychaete worm, <i>Neanthes arenaceodentata</i>	F,M,T	Copper nitrate	31	10 days	LC50	98	-	Pesch and Hoffman 1982
Polychaete worm, <i>Neanthes arenaceodentata</i>	F,M,T	Copper nitrate	31	28 days	LC50	56	-	Pesch and Hoffman 1982
Polychaete worm (21-day), <i>Neanthes arenaceodentata</i>	F,M,T	Copper chloride	29	28 days	LC50	83	-	Pesch et al. 1986
Polychaete worm (21-day), <i>Neanthes arenaceodentata</i>	F,M,T	Copper chloride	29	28 days	LC50	81	-	Pesch et al. 1986
Polychaete worm (21-day), <i>Neanthes arenaceodentata</i>	F,M,T	Copper chloride	29	28 days	LC50	86	-	Pesch et al. 1986
Polychaete worm, <i>Ophryotrocha diadema</i>	S,U	Copper chloride	FSW 98%	48 hr	LC50	100-330	-	Parker 1984
Polychaete worm, <i>Ophryotrocha diadema</i>	S,U	Copper chloride	FSW 98%	48 hr	LC50	60-80	-	Parker 1984

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Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Polychaete worm, <i>Ophryotrocha diadema</i>	S,U	Copper chloride	FSW 98%	48 hr	LC50	80-100	-	Parker 1984
Polychaete worm, <i>Ophryotrocha diadema</i>	S,U	Copper chloride	FSW 98%	48 hr	LC50	80-110	-	Parker 1984
Polychaete worm, <i>Cirriiformia spirabanchia</i>	R,U	Copper sulfate	29	26 days	LC50	40	-	Milanovich et al. 1976
Annelids (larvae), mixed species	S,U	-	-	24 hr	LC50	89	-	Reeve et al. 1976
Black abalone. <i>Haliotis cracherodii</i>	-	-	-	96 hr	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Red abalone. <i>Haliotis rufescens</i>	-	-	-	96 hr	Histopathological gill abnormalities	>32	-	Martin et al. 1977
Coral (embryos), <i>Montastraea faveolata</i>	S,U	Copper sulfate	36.0	24 hr	EC50 (normal development)	24.9	-	Rumbold and Snedaker 1997
Channeled whelk, <i>Busycon canaliculatum</i>	R,U	Copper chloride	-	77 days	LC50	470	-	Betzer and Yevich 1975
Mudsnail, <i>Nassarius obsoletus</i>	-	-	-	72 hr	Decrease in oxygen consumption	100	-	MacInnes and Thurberg 1973
Mudsnail (embryo), <i>Ilyanassa obsoleta</i>	S,U	Copper chloride	-	ca. 3 hr	Abnormal development	63.5	-	Conrad 1988
Queen conch (embryo), <i>Strombus gigas</i>	S,U	Copper sulfate	36.8	24 hr	EC50 (normal development)	21.3	-	Rumbold and Snedaker 1997
Bivalve mollusk (embryo), <i>Isognomon californicum</i>	S, U	Copper chloride	16	96 hr	LC50	7	-	Ringwood 1992
Blue mussel (1-2 cm), <i>Mytilus edulis</i>	S,U	Copper chloride	-	7 days	LC50	100-200	-	Scott and Major 1972
Blue mussel (ca, 2 cm), <i>Mytilus edulis</i>	R,U	Copper sulfate	16.5	7 days	LC50	200	-	Huilsom 1983
Blue mussel (ca, 2 cm), <i>Mytilus edulis</i>	R,U	Copper sulfate	16.5	14 days	LC50	100	-	Huilsom 1983
Blue mussel (1.0-1.5 cm), <i>Mytilus edulis</i>	F,M,T	Copper chloride	-	10 days	EC50 (growth)	6	-	Redpath 1985
Blue mussel (0.5-1.5 cm), <i>Mytilus edulis</i>	S,U	Copper sulfate	brackish	24 hr	LC50 (after 3 weeks)	420	-	Sunila and Lindstrom 1985
Blue mussel (2.0-3.0 cm), <i>Mytilus edulis</i>	S,U	Copper sulfate	brackish	24 hr	LC50 (after 3 weeks)	270	-	Sunila and Lindstrom 1985
Blue mussel (1-1.9 cm), <i>Mytilus edulis</i>	F,U	Copper sulfate	32.1	144 hr	EC20 (growth rate)	3	-	Stromgren 1986
Blue mussel (2-3.5 cm), <i>Mytilus edulis</i>	S,U	Copper sulfate	-	24 hr	Gill histopathology 1 yr later	100	-	Sunila 1986
Blue mussel (2-3.5 cm), <i>Mytilus edulis</i>	S,U	Copper sulfate	-	24 hr	Renal cysts 4 months later	200	-	Sunila 1989
Blue mussel (larvae), <i>Mytilus edulis</i>	R,U	Copper chloride	32	15 days	LC50	270	-	Beaumont et al. 1987

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Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Blue mussel (5-6 cm), <i>Mytilus edulis</i>	S,U	-	-	5 days	EC50 (filtration rate)	2	-	Grace and Gainey 1987
Blue mussel (5-6 cm), <i>Mytilus edulis</i>	S,U	-	-	96 hr	EC50 (heart rate)	170	-	Grace and Gainey 1987
Blue mussel (49.5 mm), <i>Mytilus edulis</i>	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Blue mussel (4-6 cm), <i>Mytilus edulis</i>	F,M,T	Copper chloride	35	Several hr	Halted pumping	20.8-25.6	-	Redpath and Davenport 1988
Blue mussel (7-9 cm), <i>Mytilus edulis</i>	R,U	Copper sulfate	32	20 days	LC100	150	-	Hawkins et al. 1989
Blue mussel (4.76 cm), <i>Mytilus edulis</i>	F,U	Copper sulfate	30	7 days	LOEC (scope for growth)	32	-	Sanders et al. 1991
Blue mussel (maturing), <i>Mytilus edulis</i>	R,M,T	Copper sulfate	32	1 mo	IC50 (no. spawning w/ KCl injection)	3.3	-	Stromgren and Nielsen 1991
Blue mussel (150 µm), <i>Mytilus edulis</i>	R,M,T	Copper sulfate	32	10 days	EC50 (growth)	5	-	Stromgren and Nielsen 1991
Blue mussel (5.7 cm), <i>Mytilus edulis</i>	R,U	Copper chloride	36	9 days	LC50	894	-	Weber et al. 1992
Blue mussel (5.7 cm), <i>Mytilus edulis</i>	R,U	Copper chloride	36	14 days	LC50	146	-	Weber et al. 1992
Blue mussel (embryo), <i>Mytilus edulis</i>	S,U	Copper chloride	FSW	3 days	23% fewer normal larvae	10	-	Hoare et al. 1995a
Blue mussel (embryo), <i>Mytilus edulis</i>	S,U	Copper chloride	FSW	3 days	49% fewer normal larvae	10	-	Hoare et al. 1995a
Blue mussel (embryo), <i>Mytilus edulis</i>	S,U	Copper chloride	FSW	3 days	80% fewer survivors after 5 mo	10	-	Hoare et al. 1995b
Bay scallop, <i>Argopecten irradians</i>	F,M,T	Copper chloride	27.4-31.5	42 days	EC50 (growth)	5.8	-	Pesch et al. 1979
Bay scallop, <i>Argopecten irradians</i>	F,M,T	Copper chloride	29-32	119 days	100% mortality	5	-	Zarogian and Johnson 1983
Bay scallop (31.2 mm), <i>Argopecten irradians</i>	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Giant sea scallop (107 mm ht.), <i>Placopectin magellanicus</i>	F,M	Copper sulfate	24.7	8 wk	Significant decrease in gonad weight, protein, RNA	20	-	Gould et al. 1988
Bivalve mollusk (sperm), <i>Isognomen californicum</i>	S,U	Copper chloride	16	1 hr	EC50 (fertilization)	55	-	Ringwood 1992
Eastern oyster (larva), <i>Crassostrea virginica</i>	S,U	Copper chloride	25	12 days	LC50	46	-	Calabrese et al. 1977
Eastern oyster (embryo), <i>Crassostrea virginica</i>	S,U	Copper chloride	25	-	LC50	128	-	Calabrese et al. 1973
Pearl oyster (embryos), <i>Pteria colymbus</i>	S,U	Copper sulfate	36.6	24 hr	EC50 (normal development)	<7	-	Rumbold and Snedaker 1997
Common rangia, <i>Rangia cuneata</i>	S,U	-	<1.0	96 hr	LC50	210	-	Olson and Harrel 1973

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Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Surf clam (30.4 mm), <i>Spisula solidissima</i>	F,U	Copper chloride	26	126 days	Significant increase in mortality	5	-	Nelson et al. 1988
Clam, <i>Macoma inquinata</i>	F,U	Copper sulfate	-	30 days	LC50	15.7	-	Crececius et al. 1982
Clam, <i>Macoma inquinata</i>	F,U	Copper sulfate	-	30 days	LC50	20.7	-	Crececius et al. 1982
Quahog clam (larva), <i>Mercenaria mercenaria</i>	R,U	Copper chloride	24	8-10 days	LC50	30	-	Calabrese et al. 1977
Quahog clam, <i>Mercenaria mercenaria</i>	F,M,T	-	31	11-15 wk	LC50	25	-	Shuster and Pringle 1968
Common Pacific littleneck, <i>Protothaca staminea</i>	-	-	-	17 days	LC50	39	-	Roesijadi 1980
Soft-shell clam (3.9-4.9 cm), <i>Mya arenaria</i>	S,U	Copper chloride	30	7 days	LC50	35	-	Eisler 1977
Horseshoe crab (embryo), <i>Limulus polyphemus</i>	R,U	Copper sulfate	20	72 hr	LC50	2,000	-	Botton et al. 1998
Horseshoe crab (embryo), <i>Limulus polyphemus</i>	R,U	Copper sulfate	20	72 hr	LC50	171,000	-	Botton et al. 1998
Horseshoe crab (diastula and gastrula stage embryo), <i>Limulus polyphemus</i>	R,U	Copper sulfate	-	24 hr	Total mortality	100,000	-	Itow et al. 1998
Horseshoe crab (post-gastrula embryo), <i>Limulus polyphemus</i>	R,U	Copper sulfate	-	24 hr	<50% mortality	100,000	-	Itow et al. 1998
Copepod, <i>Enidula vulgaris</i>	S,U	-	-	24 hr	LC50	192	-	Reeve et al. 1976
Copepod, <i>Euchaeta marina</i>	S,U	-	-	24 hr	LC50	188	-	Reeve et al. 1976
Copepod, <i>Metridia pacifica</i>	S,U	-	-	24 hr	LC50	176	-	Reeve et al. 1976
Copepod (24 hr), <i>Eurytemora affinis</i>	R,M,T	Copper in HNO <sub>3</sub>	FSW	96 hr	LOEC (development)	27.2	-	Sullivan et al. 1983
Copepod (24 hr), <i>Eurytemora affinis</i>	R,M,T	Copper in HNO <sub>3</sub>	FSW	96 hr	LOEC (development)	23.5	-	Sullivan et al. 1983
Copepod (24 hr), <i>Eurytemora affinis</i>	S,M,D	Copper chloride	14-16	8 days	LOEC (survival, gravid females, maturation)	-	79.9 <sup>c</sup>	Hall et al. 1997
Copepod <i>Labidocera scotti</i>	S,U	-	-	24 hr	LC50	132	-	Reeve et al. 1976
Copepod, <i>Acartia clausi</i>	S,U	Copper sulfate	FSW	48 hr	LC50	34	-	Moraitou-Apostolopoulou 1978
Copepod, <i>Acartia clausi</i>	S,U	Copper sulfate	FSW	96 hr	LC50	<10	-	Moraitou-Apostolopoulou 1978
Copepod, <i>Acartia tonsa</i>	F,U	Copper nitrate	30	6 days	LC50	9-78	-	Sosnowski et al. 1979
Copepod, <i>Acartia tonsa</i>	-	-	-	24 hr	LC50	104-311	-	Reeve et al. 1976

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Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Copepod, <i>Acartia tonsa</i>	R,U	Copper sulfate	38	10 days	Decrease mean lifespan by about 40%	1	-	Verriopoulos 1992
Copepod (adult female), <i>Tisbe holothuriae</i>	S,U	-	FSW	48 hr	LC50	80	-	Moraitou-Apostolopoulou and Verriopoulos 1982
Copepod (nauplii), mixed species	S,U	-	-	24 hr	LC50	90	-	Reeve et al. 1976
Barnacle (nauplii), <i>Balanus amphitrite</i>	S,U	Copper chloride	FSW	22-24 hr	LC50	480	-	Sasikumar et al. 1995
Barnacle (3 hr nauplii), <i>Balanus improvisus</i>	S,M,T	Copper oxide	FSW	96 hr	LC50	20	-	Koryakova and Korn 1993
Mysid shrimp, <i>Americamysis bahia</i>	S,U	Copper chloride	20	48 hr	LC50	-	423	PBS&J 1999
Mysid shrimp, <i>Americamysis bahia</i>	S,U	Copper chloride	20	48 hr	LC50	-	284	PBS&J 1999
Mysid shrimp, <i>Americamysis bahia</i>	S,U	Copper chloride	20	48 hr	LC50	-	403	PBS&J 1999
Mysid shrimp, <i>Americamysis bahia</i>	S,U	Copper chloride	20	48 hr	LC50	-	367	PBS&J 1999
Mysid (7-day), <i>Americamysis bahia</i>	R,U	Copper sulfate	20-30	7 days	LC50	169.3	-	Morrison et al. 1989
Mysid shrimp, <i>Americamysis bahia</i>	R, M, D	Copper chloride	30	96 hr	LC50	-	164	SAIC 1993
Mysid, <i>Mysidopsis bahia</i>	LC	-	30	-	Reduction in reproduction	54.1	44.9	Lussier et al. 1985
Amphipod, <i>Ampelisca abdita</i>	F	Copper nitrate	30	7 days	LC50	86.8	-	Scott et al. Manuscript
Euphausiid, <i>Euphausia pacifica</i>	S,U	-	-	24 hr	LC50	14-30	-	Reeve et al. 1976
Pink shrimp (3-5 day post larvae), <i>Penaeus duorarum</i>	S,U	Copper chloride	25	96 hr	LC50	832	-	Cripe 1994
Grass shrimp, <i>Palaemonetes pugio</i>	S,M	Copper acetate	25	96 hr	LC50	12,600	-	Curtis et al. 1979; Curtis and Ward 1981
Grass shrimp, <i>Palaemonetes pugio</i>	S,M,T	Copper acetate	25	96 hr	LC50	35,900	-	Curtis et al. 1979
Grass shrimp (<20 mm), <i>Palaemonetes pugio</i>	S,M,T	Copper sulfate	8-12	48 hr	LC50	2,100	-	Burton and Fisher 1990
Coon stripe shrimp, <i>Pandalus danae</i>	F,U	Copper sulfate	-	30 days	LC50	27.0	-	Creelius et al. 1982
Pink shrimp, <i>Pandalus montagui</i>	R,M,T	Copper chloride	-	7 days	LC50	50	-	McLeese and Ray 1986
Sand shrimp, <i>Crangon septemspinosa</i>	R,M,T	Copper chloride	-	7 days	LC50	1,400	-	McLeese and Ray 1986
American lobster (450 g adult), <i>Homarus americanus</i>	F,M,T	Copper sulfate	30	96 hr	LC50	100	-	McLeese 1974

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American lobster, <i>Homerus americanus</i>	F,M,T	Copper sulfate	30	13 days	LC50	56	-	McLeese 1974
Yellow crab (embryo), <i>Cancer anthonyi</i>	R,U	Copper chloride	34	7 days	LC50	7,080	-	Macdonald et al. 1988
Yellow crab (embryo), <i>Cancer anthonyi</i>	R,U	Copper chloride	34	7 days	28% reduction in hatching	10	-	Macdonald et al. 1988
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	Copper chloride	FSW	12 min	42% decrease in sperm motility	318	-	Young and Nelson 1974
Sea urchin (embryo), <i>Arbacia punctulata</i>	S,U	Copper sulfate	30	4 hr	EC50 (growth as thymidine incorporation)	14	-	Nacci et al. 1986
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	Copper sulfate	30	1 hr	EC50 (fertilization)	12	-	Nacci et al. 1986
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	-	30	1 hr	EC50 (fertilization)	7.3	-	Neiheisel and Young 1992
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	-	30	1 hr	EC50 (fertilization)	20.9	-	Neiheisel and Young 1992
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	-	30	1 hr	EC50 (fertilization)	11.9	-	Neiheisel and Young 1992
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	-	30	1 hr	EC50 (fertilization)	19.3	-	Neiheisel and Young 1992
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	-	30	1 hr	EC50 (fertilization)	79.2	-	Neiheisel and Young 1992
Sea urchin (sperm), <i>Arbacia punctulata</i>	S,U	Copper sulfate	30	1 hr	EC50 (fertilization)	33.3	-	Morrison et al. 1989
Rock-boring urchin (embryo), <i>Echinometra lucunter</i>	S,U	Copper sulfate	36	24 hr	EC50 (normal development)	21.9	-	Rumbold and Snedaker 1997
Sea urchin (sperm), <i>Echinometra mathaei</i>	S,U	Copper chloride	FSW	1 hr	EC50 (fertilization)	14	-	Ringwood 1992
Variegated urchin (embryo), <i>Lytechinus variegatus</i>	S,U	Copper sulfate	35.7	24 hr	EC50 (normal development)	33.8	-	Rumbold and Snedaker 1997
Green sea urchin (sperm), <i>Strongylocentrotus</i>	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	59	-	Dinnel et al. 1989
Green sea urchin (embryo), <i>Strongylocentrotus drobachianus</i>	S,M,T	Copper chloride	30	120 hr	EC50 (development)	21	-	Dinnel et al. 1989
Red sea urchin (sperm), <i>Strongylocentrotus franciscanus</i>	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	1.9	-	Dinnel et al. 1989
Sea urchin (sperm), <i>Strongylocentrotus purpuratus</i>	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	25	-	Dinnel et al. 1989
Sea urchin (embryo), <i>Strongylocentrotus purpuratus</i>	S,M,T	Copper chloride	30	120 hr	EC50 (development)	6.3	-	Dinnel et al. 1989
Sea urchin (sperm), <i>Strongylocentrotus purpuratus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	40	-	Bailey et al. 1995
Sea urchin (sperm), <i>Strongylocentrotus purpuratus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	39.4	-	Bailey et al. 1995

**Appendix C2. Other Data on Effects of Copper on Saltwater Organisms**

Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,M,T	Copper chloride	30	1 hr	EC50 (fertilization)	26	-	Dinnel et al. 1989
Sand dollar (embryo), <i>Dendraster excentricus</i>	S,M,T	Copper chloride	31	72 hr	EC50 (development)	33	-	Dinnel et al. 1989
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	20	-	Bailey et al. 1995
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	26.2	-	Bailey et al. 1995
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	10.8	-	Bailey et al. 1995
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	7.6	-	Bailey et al. 1995
Sand dollar (sperm), <i>Dendraster excentricus</i>	S,U	Copper sulfate	30	20 min	LOEC (fertilization)	16	-	Bailey et al. 1995
Arrow worm, <i>Sagitta hispida</i>	S,U	-	-	24 hr	LC50	43-460	-	Reeve et al. 1976
Atlantic menhaden, <i>Brevoortia tyrannus</i>	F,-	-	-	14 days	LC50	610	-	Engel et al. 1976
Atlantic herring (embryo), <i>Clupea harengus</i>	R,U	Copper sulfate	20	15 days	brain cell size reduced, perinuclear space increased	30	-	Abbasi et al. 1995
Atlantic herring (embryo), <i>Clupea harengus</i>	R,U	Copper sulfate	20	-	spinal deformities	50	-	Abbasi and Sheckley 1995
Pacific herring (1 hr larva), <i>Clupea harengus pailasi</i>	F,M,T	Copper chloride	-	6 days	LC50	33	-	Rice and Harrison 1978
Pacific herring (12 hr embryo), <i>Clupea harengus pailasi</i>	F,M,T	Copper chloride	-	6 days	LC50	900	-	Rice and Harrison 1978
Northern anchovy (6-10 hr embryo), <i>Engraulis mordax</i>	F,M,T,I	-	SW	25 hr	LC50	186	-	Rice and Harrison 1979
Pink salmon (4.1 cm), <i>Oncorhynchus gorbuscha</i>	S,U	Copper nitrate	16.6	5 days	LC50	563	-	Holland et al. 1960
Hardhead catfish (26-29 cm), <i>Arius felis</i>	S,U	Copper chloride	30-32	72 hr	hyperactivity	100	-	Steele 1985
Hardhead catfish (26-29 cm), <i>Arius felis</i>	S,U	Copper chloride	30-32	72 hr	7-day latent hypoactivity	100	-	Steele 1985
Hardhead catfish (26-29 cm), <i>Arius felis</i>	S,U	Copper chloride	30-32	72 hr	57% mortality after 3 weeks	100	-	Steele 1985
Atlantic cod (embryo), <i>Gadus morhua</i>	-	-	-	14 days	LC50	10	-	Swedmark and Granmo 1981
Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (survival)	253	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth)	44	-	Hughes et al. 1989



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Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth and survival)	177	-	Hughes et al. 1989
Sheepshead minnow (<24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper chloride or sulfate	30	7 days	Chronic value (growth)	177	-	Hughes et al. 1989
Sheepshead minnow (24 hr), <i>Cyprinodon variegatus</i>	R,U	Copper sulfate	32	7 days	LC50	471.5	-	Morrison et al. 1989
Sheepshead minnow (24 hr), <i>Cyprinodon variegatus</i>	R,U	Copper sulfate	32	7 days	IC50 (growth)	351.6	-	Morrison et al. 1989
Sheepshead minnow (24 hr), <i>Cyprinodon variegatus</i>	R,M,T	Copper nitrate	34-35	96 hr	LC50	>220	-	Hutchinson et al. 1994
Mummichog, <i>Fundulus heteroclitus</i>	R,U	Copper chloride	20	21 days	Histopathology (lesions)	<500	-	Gardner and LaRoche 1973
Mummichog, <i>Fundulus heteroclitus</i>	S,M,T	Copper chloride	-	96 hr	Enzyme inhibition	600	-	Jackim 1973
Mummichog (<23 days), <i>Fundulus heteroclitus</i>	S,M,T	Copper sulfate	8-12	48 hr	LC50	19,000	-	Burton and Fisher 1990
Topsmelt (sperm), <i>Atherinops affinis</i>	S,M,T	Copper chloride	-	15 min	EC50 (fertilization)	109	-	Anderson et al. 1991
Topsmelt (embryo), <i>Atherinops affinis</i>	S,M,T	Copper chloride	33	12 days	EC50 (hatching)	146	-	Anderson et al. 1991
Topsmelt (<24 hr) <i>Atherinops affinis</i>	R,M,T	Copper chloride	-	7 days	LC50	365	-	McNulty et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	-	7 days	LC50	134	-	McNulty et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	34	7 days	LC50	162	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	34	7 days	LC50	274	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	34	7 days	LC50	169.1	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	22	7 days	LC50	55.7	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	22	7 days	LC50	58.4	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	10	7 days	LC50	5.66	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	17	7 days	LC50	<10	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	25	7 days	LC50	29.9	-	Anderson et al. 1994
Topsmelt (9 day) <i>Atherinops affinis</i>	R,M,T	Copper chloride	34	7 days	LC50	53.6	-	Anderson et al. 1994

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Species	Method <sup>a</sup>	Chemical	Salinity (g/kg)	Duration	Effect	Total Concentration (µg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Inland silverside (7 day), <i>Menidia beryllina</i>	R,U	Copper sulfate	32	7 days	LC50	286.4	-	Morrison et al. 1989
Inland silverside (7 day), <i>Menidia beryllina</i>	R,U	Copper sulfate	32	7 days	IC50 (growth)	483.5	-	Morrison et al. 1989
Atlantic silverside, <i>Menidia menidia</i>	-	-	-	96 hr	Histopathological lesions	<500	-	Gardner and LaRoche 1973
Yellowtail snapper (embryo), <i>Ocyurus chrysurus</i>	S,U	Copper sulfate	36	24 hr	EC50 (viable hatch)	>250	-	Rumbold and Snedaker 1997
Sheepshead porgy (28-30 cm), <i>Archosargus probatocephalus</i>	S,U	Copper chloride	30-32	72 hr	hyperactivity	100	-	Steele 1985
Sheepshead porgy (28-30 cm), <i>Archosargus probatocephalus</i>	S,U	Copper chloride	30-32	72 hr	7-day latent hypoactivity	100	-	Steele 1985
Sheepshead porgy (28-30 cm), <i>Archosargus probatocephalus</i>	S,U	Copper chloride	30-32	72 hr	43% mortality after 3 weeks	200	-	Steele 1985
Pinfish, <i>Lagodon rhomboides</i>	S,U	-	-	14 days	LC50	150	-	Engel et al. 1976
Spotted seatrout (embryo), <i>Cynoscion nebulosus</i>	S,U	Copper sulfate	35.9	48 hr	EC50 (normal development)	118.6	-	Rumbold and Snedaker 1997
Spot, <i>Leiostomus xanthurus</i>	S,U	-	-	14 days	LC50	160	-	Engel et al. 1976
Atlantic croaker, <i>Micropogonias undulatus</i>	S,U	-	-	14 days	LC50	210	-	Engel et al. 1976
Winter flounder, <i>Pseudopleuronectes americanus</i>	F,M,T	Copper sulfate	-	14 days	Histopathological lesions	180	-	Baker 1969
Striped bass (16 days), <i>Morone saxatilis</i>	R, M		1.5	-	LC50	24		Wright 1988

a S = static; R = renewal; F = flow-through; M = measured; U = unmeasured; T = total metal concentration measured; D = dissolved metal concentration; I = ionic

b Results are expressed as copper, not as the chemical

c Dissolved copper; No other measurement reported