Table 2-2. Tributyltin effects concentrations for invertebrates

Species	Field Component?	Study Conditions	Effects Concentration[a] µg/g wet weight	Effects Concentration[a] µg/g dry weight	Effect Endpoint	Reference
Effects Observed						
Periwinkle (*Littorina littorea*)	yes	Field collected organisms from Ireland, France, and Germany	0.14[b]	0.72[c]	40% sterilization due to intersex[d]	Oehlmann et al. 1998
Snail (*Ocinebrina aciculata*)	yes	Field collected organisms from France	0.22[b]	1.1	Sterilization due to imposex	Oehlmann et al. 1996
Dogwhelk (*Nucella lapillus*)	no	Laboratory exposure to aqueous TBT	0.278[b]	1.39	100% sterilization due to imposex[d]	Gibbs et al. 1988
Periwinkle (*Littorina littorea*)	yes	Field collected organisms from German coastal waters	0.28[b,c]	1.4	60% sterilization due to intersex[d]	Bauer et al. 1997
Dogwhelk (*Nucella lapillus*)	yes	Field collected organisms from Scottish coastal waters	0.53	2.65[b]	Sterilization due to imposex	Bailey and Davies 1991
Pacific oysters (*Crassostrea gigas*)	yes	Oysters deployed in area near fish farms where cages were treated with TBT paint	0.75	3.75[b]	Reduced condition index relative to control stations (tissue weight as a percent of total weight)	Davies et al. 1988
Polychaete worm (*Neanthes arenaceodentata*)	no	Laboratory, 10-week exposure	0.940	6.27	Significant reductions in fecundity and emergent juvenile production	Moore et al. 1991
Blue mussel (*Mytilus edulis*)	no	4-day exposure under static renewal conditions; mussels were fed algal cells	1.09[b]	5.44	Reduced growth rate	Widdows and Page 1993
Dogwhelk (*Nucella lapillus*)	yes	Field transplanted mussels for 18 months to concentration up to 27.8 ng/L	1.13	3.39	Sterilization due to imposex	Bryan et al. 1987
Blue mussel (*Mytilus edulis*)	yes	Field, transplanted mussels in three field tests in San Diego Bay (one test lasted 18 weeks, two tests lasted 12 weeks)	1.2[b]	6.0	Growth rate inhibition	Salazar and Salazar 1998[e]
Blue mussel (*Mytilus edulis*)	no	4-day exposure under static renewal conditions; mussels were fed algal cells	1.86[b]	9.28	Reduced clearance rate/lethal effects	Widdows and Page 1993

Table 2-2, continued

Species	Field Component?	Study Conditions	Effects Concentration[a] µg/g wet weight	Effects Concentration[a] µg/g dry weight	Effect Endpoint	Reference
Polychaete worm (*Neanthes arenaceodentata*)	no	Laboratory, 10-week exposure	2.52	16.8	Mortality	Moore et al. 1991
Dogwhelk (*Nucella lapillus*)	no	Laboratory exposure to 107 ng/L TBT for 12 months	2.84	8.52	Sterilization due to imposex	Bryan et al. 1987
Polychaete (*Armandia brevis*)	no	Laboratory, 10-day water column exposure	6.2	41	LR50-mortality	Meador 1997
Amphipod (*Hyalella azteca*)[f]	no	1-week laboratory exposure	6.4[b]	32	Mortality	Borgmann et al. 1996
Amphipod (*Eohaustorius washingtonianus*)	no	Laboratory, 10-day water column exposure	9	43	LR50-mortality	Meador 1997
Amphipod (*Eohaustorius estuarius*)	no	Laboratory, 10-day water column exposure	12	59	LR50-mortality	Meador 1997
Clam *(Scrobicularia plana)*	no	Laboratory, 2-week sediment exposure	12.5[b]	62.5	Mortality	Langston and Burt 1991
Amphipod (*Rhepoxynius abronius*)	no	Laboratory, 10-day water column exposure	15, 16[g]	54, 59[g]	LR50-mortality	Meador 1997
Amphipod (*Hyalella azteca*)[f]	no	1-week laboratory exposure	19.6	98	Mortality	Borgmann et al. 1996
No Effects Observed						
Periwinkle (*Littorina littorea*)	yes	Field collected organisms from Ireland, France, and Germany	0.06[b]	0.30[c]	Sterilization due to intersex	Oehlmann et al. 1998
Dogwhelk (*Nucella lapillus*)	no	Laboratory exposure to aqueous TBT	0.092[b,h]	0.46	Imposex	Gibbs et al. 1988
Blue crab (*Callinectes sapidus*)	no	Laboratory exposure to TBT contaminated grass shrimp	0.11	0.55[b]	Growth	Rice et al. 1989

Table 2-2, continued

Species	Field Component?	Study Conditions	Effects Concentration[a] µg/g wet weight	Effects Concentration[a] µg/g dry weight	Effect Endpoint	Reference
Pacific oysters (*Crassostrea gigas*)	yes	Oysters deployed in area near fish farms where cages were treated with TBT paint	0.17	0.85[b]	Reduced condition index relative to control stations (tissue weight as a percent of total weight)	Davies et al. 1988
Polychaete worm (*Neanthes arenaceodentata*)	no	Laboratory, 10-week exposure	0.598[b]	2.99	Growth, reproduction	Moore et al. 1991
Blue mussel (*Mytilus edulis*)	no	4-day exposure under static renewal conditions; mussels were fed algal cells	0.792[b]	3.96	Reduced growth rate	Widdows and Page 1993
Blue mussel (*Mytilus edulis*)	yes	Field transplanted mussels in three field tests in San Diego Bay (one test lasted 18 weeks, two tests lasted 12 weeks)	0.8[b]	4.0	Growth rate inhibition	Salazar and Salazar 1998

[a] TBT ion concentration; effects concentrations were converted as necessary; concentrations in units reported by author are presented in Appendix B.
[b] Concentration calculated assuming a moisture content of 80 percent, based on the average of moisture content reported for benthic infauna and fish species (Stephan et al. 1985). For example, wet weight = 0.2 × dry weight.
[c] Value estimated from non-linear regression presented in figure in the original paper.
[d] Refers to the percent of sampled organisms that were found to be sterile because of imposex or intersex.
[e] Data presented is a reinterpretation of data originally presented in Salazar and Salazar 1988.
[f] Freshwater species.
[g] Results of two separate tests presented.
[h] No effects concentration was taken from background; therefore it may not represent the highest no effects concentration.

Table 3-1. Mercury effects concentrations for invertebrates

Species	Tissue	Mercury Speciation	Field Component?	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Effects Observed								
Daphnids (*Daphnia magna*)[a]	whole body	methyl mercury	no	Cultured organisms were exposed to 0.04 μg/L for 3 weeks in flow-through tests	2.6	Significantly reduced average number of young per test container; no effect on survival	Biesinger et al. 1982	1
Daphnids (*Daphnia magna*)[a]	whole body	mercuric chloride	no	Cultured organisms were exposed to 1.28 μg/L for 3 weeks in flow-through tests	3.6	Significantly reduced average number of young per test container; no effect on survival	Biesinger et al. 1982	1
Slipper limpet (*Crepidula fornicata*)	whole body	mercuric chloride	no	Field collected organisms exposed to 0.25 μg/L and mercury-containing algae for 16 weeks in modified flow-through tests	3.9 (females); 6.3 (males)	Significant reduction in settlement of spat during the third spawning	Thain 1984	2
Slipper limpet (*Crepidula fornicata*)	whole body	mercuric chloride	no	Field collected organisms exposed to 0.42 μg/L and mercury-containing algae for 16 weeks in modified flow-through tests	7.8 (females); 11 (males)	Significant reduction in number of larvae released during first spawning	Thain 1984	2
Amphipod (*Hyalella azteca*)[a]	whole body	assume mercuric chloride	no	Cultured organisms were exposed to 2.4 μg/L (nominal concentration was 10 μg/L) for 10 weeks in static-renewal tests	14	Significantly reduced survival, but no effect on weight or total number of young	Borgmann et al. 1993	1
Polychaete worm (*Neanthes succinea)*	whole body	mercuric chloride	no	Field collected worms exposed to 5.0 μg/L mercury in flow-through system	57.9	Reduced growth rate	Kendall 1978	3
No Effects Observed								
Grass shrimp (*Palaemonetes pugio* Holthuis)	whole body	mercuric chloride	no	Field collected organisms exposed to 50 μg/L mercury for 29 days in static bioassays	1.65	No significant increase in mortality, although 20 percent mortality was observed vs. 8 percent in the control (with 0.15 μg/g mercury)	Barthalmus 1977	4
Amphipod (*Hyalella azteca*)[a]	whole body	assume mercuric chloride	no	Cultured organisms were exposed to 1.1 μg/L (nominal concentration was 5.6 μg/L) for 10 weeks in static-renewal tests	8.8	No adverse effects on survival, weight, or total number of young	Borgmann et al. 1993	1
Polychaete worm (*Neanthes succinea)*	whole body	mercuric chloride	no	Field collected worms exposed to 2.5 μg/L mercury in flow-through system	15.5	No reduction in growth rate	Kendall 1978	3

[a] Freshwater species.

NOTE:
[1] Converted to wet weight using a ratio of 6.4 (average of NOAA [1989] and Kendall [1978] ratios).
[2] Approximate residue concentrations for weeks 6 through 10 converted to wet weight using a ratio of 6.4 (average of NOAA [1989] and Kendall [1978] ratios). No adverse effects involving reproduction or growth were observed.
[3] Concentrations converted to wet weight using average ratio of 6.06. Due to apparent high mortalities observed in the controls during this 72-day experiment (68 percent) nothing can be said about the exposure effects on survival of the worms.
[4] Shrimp were subjected to 25 shock trials during the exposure period to investigate avoidance of shock, which was significantly less than the control. The effects concentration was assumed to be reported as wet weight.

Table 3-2. Mercury effects concentrations for fish

Species[a]	Tissue	Mercury Speciation	Field Component?	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Effects Observed								
Rainbow trout (*Oncorhynchus mykiss*)	gonads	mercuric chloride	no	Flow-through adult exposures to 0.21 to 0.24 μg/L	0.10 (50 to 100 day exposure); 0.49 (400 to 528 days in same exposure)	Larval survival at 4 days post-hatch was 26 percent for fall strain and 68 percent for spring strain, and 27 percent of the alevins were teratic	Birge et al. 1979	1
Rainbow trout (*Oncorhynchus mykiss*)	gonads	inorganic mercury	no	Flow-through adult exposures to 0.7 to 0.79 μg/L	0.68 (50 to 100 day exposure); 4.57 (400 to 528 days in same exposure)	Larval survival at 4 days post-hatch was 14 percent for fall strain and 44 percent for spring strain, and 25 percent of the alevins were teratic	Birge et al. 1979	1
Larval fathead minnow (*Pimephales promelas*)	whole body	mercuric chloride	no	Cultured fish were exposed to 0.50 μg/L mercury for 30 days	1.24	Significantly reduced length compared to control	Snarski and Olson 1982	2
Larval fathead minnow (*Pimephales promelas*)	whole body	mercuric chloride	no	Cultured fish were exposed to 0.26 μg/L for 41 weeks	1.36	Significantly reduced weight in females as well as reduced length and weight in progeny	Snarski and Olson 1982	3
Rainbow trout (*Oncorhynchus mykiss*)	whole fish	methylmercury	no	Fish were injected intraperitoneally once and observed for 15 days	1.8	Body burden associated with 13 to 33 percent 15-day mortality	Hawryshyn and Mackay 1979	4
Juvenile walleye (*Stizostedion vitreum*)	whole body minus viscera	methylmercury	no	Hatchery fish fed methylmercury containing 1.0 μg/g mercury in diets for 6 months	2.37	Significant reductions in growth (length and weight) and alterations in gonadal development in male fish relative to controls	Friedmann et al. 1996	5
Larval fathead minnow (*Pimephales promelas*)	whole body	mercuric chloride	no	Cultured fish were exposed to 2.01 μg/L mercury for 60 days	4.76	Significantly reduced length and weight compared to control	Snarski and Olson 1982	6
Brook trout *(Salvelinus fontinalis*)	whole body	methylmercury	no	Hatchery fish were exposed to 0.93 μg/L for 39 weeks	9.5 (mean of dead fish)	Mortality in second generation fish; decreased hatchability; reduced juvenile weight	McKim et al. 1976	

Table 3-2, continued

Species[a]	Tissue	Mercury Speciation	Field Component?	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Fingerling rainbow trout (*Oncorhynchus mykiss*)	tissue (gill, posterior kidney, liver, gut)	methylmercury	no	Hatchery fish fed diets containing methylmercury for 84 days	10–30	Significant reductions in weight (growth) and appetite relative to controls	Rodgers and Beamish 1982	7
Subadult rainbow trout (*Oncorhynchus mykiss*)	whole body	methylmercury	no	Hatchery fish were exposed to 9 μg/L CH_3HgCl until death (approximately 32 days).	11.2	Concentration in fish that died after 12 to 33 days exposure	Niimi and Kissoon 1994	8
Fingerling rainbow trout (*Oncorhynchus mykiss*)	axial muscle	methylmercury	no	Fish were fed rations containing 16 μg/g mercury for 15 weeks	14	Mean weight gain was significantly lower than controls during the last 5 weeks of the study	Wobeser 1975	9
Fingerling rainbow trout (*Oncorhynchus mykiss*)	whole body	methylmercury	yes	Hatchery fish fed dosed shellfish meal for 269 days	19 (28 in muscle)	Symptoms of Minamata disease, including reduced body weight, appetite	Matida et al. 1971	10
Brook trout *(Salvelinus fontinalis*)	muscle tissue	methylmercury	no	Hatchery fish were exposed to 2.93 μg/L for 28 weeks	23.5 (mean of dead fish)	88 percent mortality and no spawning; 100 percent mortality of all transferred embryos	McKim et al. 1976	
Japanese medaka (*Oryzias latipes*)	eggs	mercuric chloride	no	Eggs were exposed to 15 μg/L mercuric chloride solutions for 16 days	29	Significantly reduced hatching success (20.8 percent vs. 46.7 percent in control)	Heisinger and Green 1975	11
No Effects Observed								
Juvenile walleye (*Stizostedion vitreum*)	whole body minus viscera	methylmercury	no	Hatchery fish fed methylmercury containing 0.1μg/g mercury in diets for 6 months	0.25	No effect on growth (length and weight)	Friedmann et al. 1996	
Rainbow trout (*Oncorhynchus mykiss*)	whole fish	methylmercury	no	Water exposure for 30 days	3.4	No effect on weight	Ribeyre and Boudou 1984	12
Brook trout *(Salvelinus fontinalis*)	whole body	methylmercury	no	Hatchery fish were exposed to 0.29 μg/L for 39 weeks	3.4	No reduction in survival, reproduction, or growth in three generations	McKim et al. 1976	

Table 3-2, continued

Species[a]	Tissue	Mercury Speciation	Field Component?	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Fingerling rainbow trout (*Oncorhynchus mykiss*)	axial muscle	methylmercury	no	Fish were fed rations containing 8 μg/g mercury for 15 weeks	12	No effect on mean weight gain, mortality, or appetite	Wobeser 1975	
Japanese medaka (*Oryzias latipes*)	eggs	mercuric chloride	no	Eggs were exposed to 10 μg/L mercuric chloride solutions for 16 days	16	No adverse effect on hatching success	Heisinger and Green 1975	

[a] All are freshwater species.

NOTE:

[1] Embryos and alevins were maintained in mercury-free control water. After 400 days, eggs contained mercury concentrations of 0.26 and 3.67 μg/g in the 0.2 and 0.7 μg/L exposures respectively.

[2] Fish exposed to 1.02, 2.01, and 3.69 μg/L with body burdens of 2.64, 4.76, and 7.60 μg/g also exhibited reduced length. No significant differences in survival were observed. Fish were fed Artemia diets. In separate experiments, fish fed dry trout starter and exposed to 4.51 μg/L mercuric chloride had significantly reduced survival with 4.18 μg/g mercury body burdens.

[3] Only 3 of 8 females spawned (compared to 8 of 8 in control). None of the females spawned after exposure to 1.02 μg/L for 41 weeks (body burden of 4.47 μg/g). Note that after 41 weeks, body burdens were approximately twice those in the 60-day exposures at the same exposure concentration.

[4] The effect body burdens were calculated using the linear regression equation presented (y=0+0.91x) where y is the body burden (μg/g mercury in fish) and x is the dose administered (μg/g mercury). Doses of 2 and 4 μg/g mercury resulted in mortality ranging from 13 to 33 percent in two different experiments.

[5] Female fish were not affected even in the 1.0 μg/g mercury dose group.

[6] Fish were fed Artemia. Fish fed with dry trout starter exhibited reduced length and weight after 60-day exposures to 0.58 to 4.51 μg/L and reduced survival and increased spinal deformity in the 4.51 μg/L exposure. Body burdens of mercury in these fish ranged from 1.31 μg/g in the 0.58 μg/L exposure to 4.18 μg/g in the 4.51 μg/L exposure.

[7] Fish weight was significantly reduced in fish fed 95 μg/g mercury ad lib. compared to control fish fed 0 μg/g mercury ad lib.; fish weight and growth rate was significantly reduced in fish fed 25 and 75 μg/g mercury with meal sizes 2 percent of fish wet weight relative to control fish fed the same meal size but with no mercury.

[8] Fish began dying on approximately day 12 with 100 percent mortality by approximately day 32. Note that the study confirmed an increase in lethal body burden with increased time to death.

[9] Significant differences in weight gain were not observed in fish fed diets containing 8 μg/g methylmercury (up to 12 μg/g body burdens). No mercury-related mortality or differences in appetite were observed even in fish containing 31 μg/g.

[10] By day 249, each fish had been fed a 22.9 g of meal containing a total of 1.41 mg of methylmercury. Other symptoms included dark color, disability to catch food, poor coordination.

[11] Hemorrhaging, blood vessel deterioration and loss of blood cells were observed in eggs incubated in 15 μg/L mercury solution. No effects were observed in eggs exposed to 10 μg/L mercury with 16 μg/g body burdens. None of the eggs containing 54 μg/g hatched.

[12] The body burden was significantly lower (0.6 vs. 3.4 μg/g) when fish were exposed to mercuric chloride vs. methylmercuric chloride for 30 days. No effect on weight was observed in either exposure.

Table 4-1. Polychlorinated biphenyl effects concentrations for invertebrates

Species	Tissue	PCB Type	Field Component?	Study Conditions	Effects Concentration (µg/g wet weight)	Effect Endpoint	Reference	Note
Effects Observed								
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1016	no	Water exposure of 0.4 µg/L (1 µg/L nominal) for 4 days	1.1	33 percent mortality relative to 8 percent in the control	Hansen et al. 1974	
Juvenile pink shrimp (*Penaeus duorarum*)	whole body	Aroclor 1254	no	Water exposure of 100 µg/L (nominal) for 48 hours	3.9	100 percent mortality	Duke et al. 1970	
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	no	Water exposure of 4.0 µg/L for 16 days	27	45 percent average mortality	Nimmo et al. 1974	
American oyster (*Crassostrea* virginica)	whole body	Aroclor 1016	no	Water exposure of 7.2 µg/L (10 µg/L nominal) for 4 days	32	38 percent reduction in shell growth	Hansen et al. 1974	
American oyster (*Crassostrea virginica*)	whole body	Aroclor 1254	no	Water exposure of 10 µg/L (nominal) for 96 hours	33	41 percent reduction in shell growth rate	Duke et al. 1970	1
Brown shrimp (*P. aztecus*)	whole body	Aroclor 1016	no	Water exposure of 8.9 µg/L (10 µg/L nominal) for 4 days	42	43 percent mortality relative to 0 percent in the control	Hansen et al. 1974	
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	no	Water exposure of 9.1 µg/L for 7 days	65	60 percent average mortality	Nimmo et al. 1974	
Young American oysters (*Crassostrea virginica*)	whole body	Aroclor 1254	no	Exposure to 5 µg/L Aroclor 1254 in flowing, unfiltered seawater for 24 weeks	425	Significantly reduced height and weight of oysters; survival was not affected	Lowe et al. 1972	2, 3, 4
No Effects Observed								
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	yes	Field exposure from Nov. to Feb. in special cages to sediment containing 5 µg/g dry weight (in upper two inches)	0.42	No effect on survival	Nimmo et al. 1974	5
Juvenile pink shrimp (*Penaeus duorarum*)	whole body	Aroclor 1254	no	Water exposure of 10 µg/L (nominal) for 48 hours	1.3	No effect on survival	Duke et al. 1970	
Marine clams (*Macoma nasuta*)	whole soft tissues	Sum of 13 congeners	no	Clams were exposed to sediment spiked with 13 congeners (and hexachlorobenzene) for 119 days	1.3	No effect on mortality or growth	Boese et al. 1995	6
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	no	Water exposure of 0.62 µg/L for 7 days	5.4	No effect on survival	Nimmo et al. 1974	

Table 4-1, continued

Species	Tissue	PCB Type	Field Component?	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	no	Water exposure of 0.62 μg/L for 35 days	16.48	No effect on survival	Nimmo et al. 1974	5
Grass shrimp (*Palaemonetes pugio*)	whole body	Aroclor 1254	no	Water exposure of 1.3 μg/L for 16 days	18	No effect on survival	Nimmo et al. 1974	
Juvenile blue crabs (*Callinectes sapidus*)	whole body	Aroclor 1254	no	Water exposure of 5 μg/L (nominal) for 20 days	23	No effect on survival	Duke et al. 1970	1
Amphipod (*Hyalella azteca*)[a]	whole body	Aroclor 1242	no	Water exposure of 18 to 27 μg/L for 10 weeks	28.4	No effect on survival or weight	Borgmann et al. 1990	
Young American oysters (*Crassostrea virginica*)	whole body	Aroclor 1254	no	Exposure to 1 μg/L Aroclor 1254 in flowing, unfiltered seawater for 30 weeks	101 (average)	No significant reductions in growth or survival	Lowe et al. 1972	2, 3

[a] Freshwater species.

NOTE:

1. Body burden in oysters after 4 days in water without added PCBs. Note 100 percent reduction in shell growth in oysters exposed to 100 μg/L for 96 hours.
2. Packed columns were used for PCB analysis.
3. Atrophy of digestive diverticular epithelium and degeneration of vesicular connective tissues concomitant with leukocytic infiltration were also observed.
4. The mean weight and height of the control oysters were significantly greater than those of the PCB-exposed oysters after 6 weeks and thereafter throughout the experiment (both increased with time in control and experimental oysters).
5. Concentrations of Aroclor 1254 in *P. pugio* after exposure to contaminated sediments for 3 months were equivalent to lab exposure of 0.09 μg/L for 2 weeks.
6. The 13 PCB congeners were 18, 52, 101, 105, 118, 128, 138, 151, 153, 170, 180, 194, and 209. The PCBs concentration in spiked sediment was 0.65 μg/g dry weight with 0.80 percent total organic carbon. A moisture content of 85 percent was assumed for the clams to convert from dry weight to wet weight.

Table 4-2. Polychlorinated biphenyl effects concentrations for fish—studies with a field component

Species	Tissue	PCB Type	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
Effects Observed							
Baltic flounder (*Platichthys flesus*)	ovary	Total PCB	Eggs from field-collected fish were stripped, artificially inseminated, and incubated in lab	0.12	Viable hatch reduced($p < 0.01$)	Von Westernhagen et al. 1981	1
Lake trout (*Salvelinus namaycush*)[a]	eggs	sum of 113 congeners	Observation of eggs from feral fish from southeast Lake Michigan	3	Reduced egg hatchability	Mac and Schwartz 1992	2
Chinook salmon (*Oncorhynchus tshawytscha*)[a]	eggs	Total PCB	Observation and analysis of feral fish and eggs from Lake Michigan	4.2	Reduced hatching success	Ankley et al. 1991	3
Adult fathead minnow (*Pimephales promelas*)[a]	tissue	Aroclor 1254	Exposed to PCBs in sediment for 16 weeks	13.7	Reduced fecundity and frequency of reproduction	ACOE 1988	4
Adult cyprinid minnow (*Phoxinus phoxinus*)[a]	whole body	Clophen A50	Baltic Sea fish fed PCB contaminated food for 40 days	15	Premature hatching, reduced survival of fry	Bengtsson 1980	
Adult cyprinid minnow (*Phoxinus phoxinus*)[a]	whole body	Clophen A50	Baltic Sea fish fed PCB contaminated food for 40 days	170	Decreased number and hatchability of ova; delayed spawning; premature hatching	Bengtsson 1980	
No Effects Observed							
Atlantic salmon (*Salmo salar*)[a]	eggs	Aroclor 1254	Observation of contaminated field-collected fish and their eggs	0.42	No effect on hatchability	Zitko and Saunders 1979	5
Lake trout (*Salvelinus namaycush*)[a]	eggs	sum of 113 congeners	Observation of eggs from feral fish from southeast Lake Michigan	2.8	Reduced egg hatchability	Mac and Schwartz 1992	2
Chinook salmon (*Oncorhynchus tshawytscha*)[a]	eggs	Total PCB	Observation and analysis of feral fish and eggs from Lake Michigan	3.7	Reduced hatching success	Ankley et al. 1991	3
Adult fathead minnow (*Pimephales promelas*)[a]	tissue	Aroclor 1254	Exposed to PCBs in sediment for 16 weeks	11.6	Reduced fecundity and frequency of reproduction	ACOE 1988	4

Table 4-2, continued

[a] Freshwater species.

NOTE:

[1] Chlorinated hydrocarbons and metals were also elevated in some fish, but did not correlate significantly with viable hatch. PCB concentration identified as a tentative threshold.

[2] Egg hatchability was negatively correlated with total PCBs in eggs (R2=0.48, n=24). This correlation was better than with the TCDD toxic equivalent using toxic equivalency factors from Safe (1990).

[3] Fish were collected from Lake Michigan. Study sample size was small (n= 10).

[4] Sediments were collected from the Sheboygan Harbor (0.82, 14.0, and 27.0 μg/g dry weight Aroclor 1254). Significant effects were observed in the two higher concentration exposures.

[5] Body burden was reported on a per-lipid basis and was converted based on a conversion that was applied to another study in the report. Hexachlorbenzene, DDE, DDD, DDT, dieldrin, and trans-nonachlor were also measured in the fish, which were collected from the Big Salmon River in New Brunswick.

Table 4-3. Polychlorinated biphenyl effects concentrations for fish—laboratory studies

Species	Tissue	PCB Type	Study Conditions	Effects Concentration (µg/g wet weight)	Effect Endpoint	Reference	Note
Effects Observed							
Yearling coho salmon (*Oncorhynchus kisutch*)	liver	Aroclor 1254	Hatchery fish were injected with 150 µg/kg just prior to smoltification	0.5–1.2	6 percent mortality after 5 days in seawater	Folmar et al. 1982	1
Rainbow trout (*Oncorhynchus mykiss*)[a]	eggs	Aroclor 1254	Gravid females fed 200 µg/g for 60 days	1.6	Reduced growth of fry relative to control ($p < 0.001$)	Hendricks et al. 1981	
Atlantic salmon (*Salmo salar*)	whole body	1:1:1:1 mixture of Aroclors 1016, 1221, 1254, 1260	Water exposure of eyed embryos for 48 hours to 6.25 mg/L	3	Wet weight of alevins 59 days post exposure was significantly lower than that of controls	Fisher et al. 1994	2
Sheepshead minnow (*Cyprinodon variegatus*)	eggs	Aroclor 1254	Exposure of parent fish to 0.14 µg/L for 28 days	7.0	Decreased fry survival in the first week after hatch	Hansen et al. 1973	
Fingerling channel catfish (*Ictalurus punctatus*)[a]	whole fish minus stomach	Aroclor 1242	Fed 20 µg/g in diet for 130 days	14.33	Reduced weight gain (mean weight of treated fish only 60 percent of mean weight of control fish)	Hansen et al. 1976	
Brook trout (*Salvelinus fontinalis*)[a]	back muscle, eggs	Aroclor 1254	Water exposure of 0.2 mg/L for 21 days	32.8 (77.9 in eggs)	78 percent egg hatch compared to 100 percent in control	Freeman and Idler 1975	3
Spot (*Leiostomus xanthurus*)	whole body	Aroclor 1254	Water exposure of 5 µg/L for 20 days	46	Mortality	Hansen et al. 1971	4
Pinfish (*Lagodon rhomboides*)	whole body	Aroclor 1016	Water exposure of 21 µg/L (32 µg/L nominal) for 33 days	106	Significant reduction in survival (50 percent mortality relative to 6 percent in control)	Hansen et al. 1974	5
Young rainbow trout (*Oncorhynchus mykiss*)[a]	whole body	1:2 ratio of Aroclor 1254:1260	Water exposure of 2.9 µg/L for 90 days	120	reduced growth after 90 days exposure	Mayer et al. 1985	6
Brook trout (*Salvelinus fontinalis*)[a]	dead fry	Aroclor 1254	Water exposure of eggs to 3.1 to 13 µg/L for 10 days prior to hatch and 118 days after	125	Fry mortality; 21 to 100 percent mortality	Mauck et al. 1978	7
Sheepshead minnow (*Cyprinodon variegatus*)	fry whole body	Aroclor 1016	Exposed to 32 µg/L in intermittent-flow bioassay	200	Significantly reduced fry survival	Hansen et al. 1975	8
1.9 g goldfish (*Carassius auratus*)[a]	whole body	Aroclor 1254	Water exposure of 0.5-4 mg/L for 5 to 21 days	250–324	Mortality	Hattula and Karlog 1972	9

Table 4-3, continued

Species	Tissue	PCB Type	Study Conditions	Effects Concentration (μg/g wet weight)	Effect Endpoint	Reference	Note
3-spined stickleback (*Gasterosteus aculeatus*)[a]	carcass	Clophen A50	Fed PCB-containing chironomids for 3.5 months	289 (after spawning)	Reduced spawning success (25 percent vs. 80 percent in control, not statistically significant)	Holm et al. 1993	10
Fathead minnow (*Pimephales promelas*)[a]	terminal residue	Aroclor 1254	PCB exposure in continuous flow aquaria water	429 (female)	Reduced spawning, but egg hatchability and fry survival were not affected	Nebeker et al. 1974	
Fingerling coho salmon (*Oncorhynchus kisutch*)[a]	whole body	Aroclor 1254	Fed 480 μg/g in diet for 260 days	645	Mortality	Mayer et al. 1977	11
No Effects Observed							
14 -week old Rainbow trout (*Oncorhynchus mykiss*)[a]	whole body	Aroclor 1254	Fed 15 μg/g in diet for 32 weeks	8	No effect on growth or survival	Lieb et al. 1974	
Juvenile pinfish (*Lagodon rhomboides*)	whole body	Aroclor 1254	Exposed to 100 μg/L (nominal) for 48 hours	17	100 percent survival	Duke et al. 1970	
Fingerling channel catfish (*Ictalurus punctatus*)[a]	whole body	4 Aroclors	Fed 2.4 to 24 μg/g in diet for 193 days	32	Growth or mortality (1254 increased thyroid activity)	Mayer et al. 1977	

[a] Freshwater species.

NOTE:

[1] PCB concentrations in liver two weeks after injection. Saltwater adaptation was also adversely affected.

[2] Residue concentration is estimated from a figure and was measured 53 days post exposure. No significant differences were observed in hatching success or survival, although photoreactivity was reduced.

[3] Note that none of the eggs hatched in water containing 0.2 mg/L PCBs and 3.8 mg/L Corexit 7664, which was present in a control and the PCB exposure tank.

[4] Note that mortality did not appear directly related to the body burden, rather the body burden increased with exposure duration. Although mortality of spot (51 to 62 percent) was similar in three tests of different duration (20 to 45 days), the body burden (46 to 152 μg/g) increased with exposure duration.

[5] In a 42-day exposure, 13 μg/L measured in water resulted in 44 percent mortality and a body burden of 620 μg/g, whereas an 18 day exposure of 59 μg/L resulted in 50 percent mortality and a body burden of 205 μg/g.

[6] Growth was significantly reduced after 90 days and there was a trend toward increased mortality although it was not significantly different.

[7] Median hatching time, egg hatchability, and sac fry survival were not affected. Larval growth was initially decreased, but not by the end of the test at 118 days.

[8] Fertilization success, survival of embryos to hatching, and survival of fry for 2 weeks were not affected when eggs contained up to 77 μg/g Aroclor 1016.

[9] PCB concentrations are lethal body burdens.

[10] Chemical analysis of carcass after dissection of head, viscera, and spines. Statistical significance was assessed using a chi-square test ($P<0.05$).

[11] Fish with 650 μg/g began dying at day 260 and all were dead within 5 days.