Attachment 8 Acceptable Toxicity Studies for the Selection of Fish Toxicity Reference Values

Table 1. Acceptable toxicity studies for selection of fish dietary toxicity reference values

Chemical	Chemical Form	Test Species	Life Stage	NOAEL (mg/kg dw[a])	LOAEL (mg/kg dw[a])	Exposure Route	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Arsenic	sodium arsenite	rainbow trout	juvenile	20[b]	30[b]	food	6 wks	growth	body weight	Oladimeji et al. (1984)	concentrations in figure and text do not agree in study: 20 mg/kg is mentioned both as an effect level and a NOAEL in the text; however, it is shown in the figure to be not significant; 20 mg/kg = assumed NOAEL; food consumption not measured; fish fed prepared diet treated with chemical salts; only the nominal concentration was reported
Arsenic	disodium arsenate heptahydrate	rainbow trout	juvenile	8	44	food	16 wks	growth	body weight	Cockell et al. (1991)	feed refusal accompanied effects; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate heptahydrate	rainbow trout	juvenile		49	food	24 wks	growth	body weight	Cockell et al. (1991)	feed refusal accompanied effects; effects attributed to feed refusal; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate heptahydrate	rainbow trout	juvenile		55	food	8 days	growth	body weight	Cockell et al. (1992)	feed refusal accompanied effects; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate	rainbow trout	juvenile		58	food	12 days	growth	body weight	Cockell and Bettger (1993)	feed refusal accompanied effects; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate heptahydrate	rainbow trout	juvenile	32	60	food	12 days	growth	body weight	Cockell et al. (1992)	feed refusal accompanied effects; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate heptahydrate	rainbow trout	juvenile	33	65	food	24 wks	growth	body weight	Cockell et al. (1991)	feed consumption did not differ from controls; body weight gain reduced at 12 weeks in fish fed 33 mg/kg arsenic but not at 24 weeks (body weight was recovered); fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate	rainbow trout	juvenile		137	food	8 days	growth	body weight	Cockell and Hilton (1988)	greater than 10% mortality at LOAEL; feed refusal accompanied effects; study also reported effects of organic arsenic which was not toxic at high levels; fish fed prepared diet treated with chemical salts
Arsenic	arsenic trioxide	rainbow trout	juvenile		180	food	8 days	growth	body weight	Cockell and Hilton (1988)	feed refusal accompanied effects; greater than 10% mortality at LOAEL; study also reported effects of organic arsenic which was not toxic at high levels; fish fed prepared diet treated with chemical salts
Arsenic	disodium arsenate heptahydrate	striped bass	juvenile	52.3	188.8	food	6 days	growth	body weight	Blazer et al. (1997)	feed refusal accompanied effects; fish fed prepared diet treated with chemical salts
Cadmium	$Cd(NO_3)_2$	rockfish	juvenile	0.1[c]	0.5	food	60 days	growth	body weight and length growth rate; condition factor	Kim et al. (2004); Kang et al. (2005)	body weight and body length growth rate were significantly affected in both studies at 25 and 125 mg/kg dw; significance of effect on body weight and body length growth rate at 0.5 and 5 mg/kg dw was not consistent between the two studies; condition factor was reduced at all diet concentrations (0.5, 5, 25, and 125 mg/kg), but was not significant at 25 mg/kg; a significant inverse relationship was observed between weight gain and the exposure concentration of dietary Cd at 25 and 125 mg/kg dw; fish fed prepared diet treated with chemical salts
Cadmium	cadmium chloride	rainbow trout	fry	55[b]		primarily food	60 days	survival, growth	100% survival, body weight and length	Mount et al. (1994)	fish exposed to copper, cadmium, lead, and zinc in water at 23.0, 0.97, 3.32, and 46.3 µg/L in addition to dietary exposure; only no-effect reported; fish fed *Artemia* exposed to cadmium chloride in water; dietary concentrations corrected for a theoretical 20% loss resulting from depuration of copper from *Artemia.*
Cadmium	$Cd(NO_3)_2$	rockfish	juvenile	125		food	60 days	survival		Kim et al. (2004)	fish fed prepared diet treated with chemical salts
Cadmium		guppy		171[b]		food	10-30 days	growth		Hatakeyama and Yasuno (1982)	fed exposed *Monia macrocopa,* significant growth effect at day 10 disappeared at day 20 in fish fed 126 and 171 µg/g dw; fish fed prepared diet treated with chemical salts
Cadmium	cadmium chloride	guppy	adult	210[b]		food	2 mo	reproduction	# live fry, fry mortality, premature embryos	Hatakeyama and Yasuno (1987)	fed exposed *Chironomus yoshimatsui* (midge larvae), no reproductive effect after 2 mo

Chemical	Chemical Form	Test Species	Life Stage	NOAEL (mg/kg dw[a])	LOAEL (mg/kg dw[a])	Exposure Route	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Cadmium		Atlantic salmon	juvenile	250		food	4 months	growth	growth rate (body weight)	Lundebye et al. (1999)	fish fed prepared diet treated with chemical salts
Cadmium	cadmium chloride	guppy	2 mo	274[b]		food	30 days	growth	body weight	Hatakeyama and Yasuno (1987)	fed exposed *Chironomus yoshimatsui* (midge larvae), no growth effect by day 30
Cadmium		rainbow trout	juvenile	294		food	15-30 days	growth, survival	specific growth rate, survival	Baldisserotto et al. (2005)	fish fed prepared diet treated with chemical salts
Cadmium		rainbow trout	juvenile	471		food	28 days	survival, growth	growth rate, survival	Franklin et al. (2005)	fish fed prepared diet treated with chemical salts
Cadmium	cadmium chloride	guppy	30 day old	500[b]	800[b]	food	7 mo	reproduction	cumulative number of fry produced	Hatakeyama and Yasuno (1987)	fed exposed *Chironomus yoshimatsui* (midge larvae); cumulative number of fry decreased to about 60% of the control in fish exposed to 80 and 160 µg/L; no discussion of statistics; LOAEL and NOAEL are estimated using figure, no replication
Cadmium	cadmium chloride	guppy	30 day old		1,250[b]	food	7 mo	growth, survival	female growth, female survival	Hatakeyama and Yasuno (1987)	fed exposed *Chironomus yoshimatsui* (midge larvae); female body weight decreased - 68% of control at the 48th day in fish exposed to 160 µg/L; 6 of 7 females died that were exposed to 160 µg/L; no discussion of statistics- unclear on growth effects at the other doses; LOAEL is estimated using figure; no effect on male growth, no replication
Cadmium	cadmium nitrate	rainbow trout	juvenile	786	1,395	food	30 days	survival		Szebedinsky et al. (2001)	57% survival observed in fish fed 1,395 mg/kg; in a separate experiment reported in this study, 92% survival was reported for juvenile rainbow trout exposed to dietary cadmium concentrations of 1,419 mg/kg dw over a 36-day exposure period; survival data were not statistically analyzed in either experiment
Cadmium	cadmium nitrate	rainbow trout	juvenile	1,395	2,265	food	30 days	growth	specific growth rate (weight)	Szebedinsky et al. (2001)	
Cadmium	cadmium sulfate	rainbow trout			10,000	food	28 days	survival		Handy (1993)	39% (14 of 36) mortality between day 3 and 23 of exposure period; fish fed prepared diet treated with chemical salts
Chromium	chromium (III)	grey mullet	2 yrs old	9.42		food and sediment	8 wks	growth		Walsh et al. (1994)	significant increase in growth of the chromium-exposed fish (not an adverse effect); gray mullet consume large amounts of sediment during feeding and fish were exposed to chromium in both diet and sediments (46mg/kg) simultaneously
Copper	copper	channel catfish	fingerling	8	16	food	16 wks	growth	body weight	Murai et al. (1981)	significant effects at 4 wks in 16- and 32-mg/kg treatments; growth gain per feed consumed was significantly lower for fish fed 8 mg/kg; fish fed prepared diet treated with chemical salts
Copper	copper sulfate pentahydrate	channel catfish	fingerling	40		food	13 wks	growth	body weight	Gatlin and Wilson (1986)	fish fed prepared diet treated with chemical salts
Copper	copper sulfate	rockfish	juvenile	50	100	food	60 days	growth	body weight (growth rate)	Kang et al. (2005)	fish fed prepared diet treated with chemical salts
Copper	copper sulfate pentahydrate	Atlantic salmon	parr	98		food	12 wks	growth, survival	survival, condition factor, body weight,	Lorentzen et al. (1998)	
Copper	copper sulfate	rainbow trout		200		food	32 days	survival		Handy (1992)	only no-effect level concentration reported; fish fed prepared diet treated with chemical salts.
Copper	copper sulfate pentahydrate	rainbow trout		664[b]		food	24 wks	growth		Lanno et al. (1985b)	significant effects at 16 wks; at 24 wks, growth effects no longer apparent; only no-effect level concentration reported; fish fed prepared diet treated with chemical salts
Copper	copper sulfate	rainbow trout		684		food	42 days	growth		Miller et al. (1993)	only no-effect level concentration reported; fish fed prepared diet treated with chemical salts
Copper	copper sulfate pentahydrate	Atlantic salmon	parr	691.3[b]		food	4 wks	growth	length, weight, or condition factor	Berntssen et al. (1999b)	only no-effect level concentration reported; fish fed prepared diet treated with chemical salts
Copper	copper sulfate pentahydrate	Atlantic salmon	fry	500	700	food	3 mos	growth		Lundebye et al. (1999)	fish fed prepared diet treated with chemical salts

Chemical	Chemical Form	Test Species	Life Stage	NOAEL (mg/kg dw[a])	LOAEL (mg/kg dw[a])	Exposure Route	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Copper	copper sulfate pentahydrate	rainbow trout		287[b]	730[b]	food	8 wks	growth		Lanno et al. (1985b)	feed refusal and 19% mortality was observed at 1,585 mg/kg-diet; fish fed prepared diet treated with chemical salts
Copper	copper sulfate pentahydrate	rainbow trout		730[b]		food	8 wks	survival		Lanno et al. (1985b)	study showed potential effects at higher concentrations- confounded by food avoidance; feed refusal and 19% mortality were observed at 1,585-mg/kg diet; only no-effect level concentration reported; fish fed prepared diet treated with chemical salts
Copper	copper sulphate pentahydrate	rainbow trout			796[b]	food	16 wks	growth		Lanno et al. (1985a)	fish were fed on control diet for 12 d after exposure period; fish fed prepared diet treated with chemical salts
Copper	copper chloride	rainbow trout	fry	352[b]		primarily food	60 days	survival	survival	Mount et al. (1994)	fish exposed to copper, cadmium, lead, and zinc in water at 23.0, 0.97, 3.32, and 46.3 µg/L in addition to dietary exposure; mortality observed in fish fed *Artemia* with Cu concentrations of 830 mg/kg was attributed to elevated copper concentrations in the water; fish fed live Artemia exposed to copper chloride in water; dietary concentrations corrected for a theoretical 20% loss resulting from depuration of copper from *Artemia*
Copper	copper sulfate	Atlantic salmon		638[b]	868[b]	food	3 mo	growth		Berntssen et al. (1999a)	fish fed prepared diet treated with chemical salts
Copper	copper chloride	rainbow trout	fry	800[b]		primarily food	60 days	growth	body weight and length	Mount et al. (1994)	fish exposed to copper, cadmium, lead, and zinc in water at 23.0, 0.97, 3.32, and 46.3 µg/L in addition to dietary exposure; only no-effect level concentration reported; fish fed live *Artemia* exposed to copper chloride in water; dietary concentrations corrected for a theoretical 20% loss resulting from depuration of copper from *Artemia*
Copper	copper sulfate pentahydrate	rainbow trout		1,042		food	28 days	survival/ growth		Kamunde et al. (2001)	non-significant growth inhibition at NOAEL; only no-effect level concentration reported; fish fed prepared diet
Copper	copper sulfate pentahydrate	grey mullet			2,397[b]	food	67 days	growth		Baker et al. (1998)	effects associated with reduced feeding
Copper	copper sulfate	rainbow trout		10,000		food	28 days	survival		Handy (1993)	only no-effect level concentration reported; fish fed prepared diet treated with chemical salts
Lead	lead nitrate	rainbow trout	fry	210[b]		primarily food	60 days	survival, growth	100% survival, body weight and length	Mount et al. (1994)	fish exposed to copper, cadmium, lead, and zinc in water at 23.0, 0.97, 3.32, and 46.3 µg/L in addition to dietary exposure; fish fed live *Artemia* exposed to lead nitrate in water
Lead		rainbow trout		7,040		food		growth		Goettl et al. (1976)	fish fed prepared diet treated with chemical salts
Silver		rainbow trout		3000		food		growth		Galvez and Wood (1999)	fish fed prepared diet treated with chemical salts
Vanadium	sodium orthovanadate	rainbow trout	juvenile	2.04[d]	10.2	food	12 wks	growth	body weight	Hilton and Bettger (1988)	reduced feeding at all doses but significant increase in food consumption/weight gain
Zinc	zinc chloride	rainbow trout	fry	1,900[b]		primarily food	60 days	growth, survival	body weight and length; 97% survival	Mount et al. (1994)	fish exposed to copper, cadmium, lead, and zinc in water at 23.0, 0.97, 3.32, and 46.3 µg/L in addition to dietary exposure. fish fed live *Artemia* exposed to zinc chloride in water
Zinc		rainbow trout	fingerling	1,000	2,000	food	6 wks	growth		Takeda and Shimma (1977)	fish fed at same dose zinc with 0.5% Ca experienced no adverse effects.
Benzo(a)pyrene		areolated grouper	juvenile	81		food	4 wks + 4 wks recovery	survival, growth	survival, body weight & length	Wu et al. (2003)	exposure was dietary force feeding - fish were force fed pellet into larynx
Benzo(a)pyrene		English sole	juvenile	47	116	food	10-12 days	growth		Rice et al. (2000)	diet of exposed polychaetes exposed for 28 d; exposure concentrations calculated from feeding rates
Benzo(a)pyrene		rainbow trout	juvenile	100	1,000	food	28 days	growth		Hart and Heddle (1991)	fish fed prepared diet treated with benzo(a)pyrene
Benzo(a)pyrene		rainbow trout	3 mo. old		1,000	food	18 mo	growth	reduced body weight	Hendricks et al. (1985)	fish fed prepared diet treated with benzo(a)pyrene; total mortality was higher in the control group
Benzo(a)pyrene		rainbow trout	juvenile (3 mos old)	1,000		food	18 mo	survival		Hendricks et al. (1985)	mortality was greater in control; NOAEL supported by additional 9-week study; fish fed prepared diet treated with benzo(a)pyrene

CHEMICAL	CHEMICAL FORM	TEST SPECIES	LIFE STAGE	NOAEL (mg/kg dw[a])	LOAEL (mg/kg dw[a])	EXPOSURE ROUTE	EXPOSURE DURATION	ENDPOINT	ENDPOINT EFFECT	SOURCE	NOTES
PAHs	PAH mixture[a]	chinook salmon	juvenile	280[b]		food	7 wks	growth		Palm et al. (2003)	14 PAHs included in diet: acenaphthene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene
PAHs	PAH mixture[a]	chinook salmon	juvenile	280[b]		food	4 wks exposure, 2 wks immuno-challenge	disease resistance		Palm et al. (2003)	14 PAHs included in diet: acenaphthene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene; fish were exposed to *Listonella anguillarum* following PAH exposure. No difference was observed between PAH-exposed fish and controls in either fish that were vaccinated against the bacterium or those that weren't vaccinated
PAHs	PAH mixture	chinook salmon	juvenile	324	951	food	53 days	growth	reduced dry-weight body weight	Meador et al. (2006)	21 PAHs included in diet: naphthalene, 2-methylnaphthalene, dimethylnaphthalene, dibenzothiophene, acenaphthene, fluorene, 1,8-dimethyl(9H)fluorene, phenanthrene, 9-ethylphenanthrene, 9-ethyl-10-methylphenanthrene, 1-methyl-7-isopropylphenanthrene, anthracene, fluoranthene, pyrene, methyl pyrene, benzo(a)anthracene, chrysene, benz(a)pyrene, benzo(k)fluoranthene, benzo(g,h,i)perylene, and dibenzanthracene

[a] Concentrations of elemental metal or specific PAH chemical. Except where noted, concentrations were as administered, and were assumed to approximate a dry weight concentration.

[b] Converted to dry weight basis based on moisture content reported in paper.

[c] NOAEL estimated using uncertainty factor of 5 (chronic LOAEL to chronic NOAEL).

[d] NOAEL estimated using uncertainty factor of 10 (acute LOAEL to chronic NOAEL).

LOAEL – lowest-observed-adverse-effect level

NOAEL – no-observed-adverse-effect level

PAH – polycyclic aromatic hydrocarbon

Table 2. Acceptable toxicity studies for selection of fish whole-body tissue residue TRVs

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
2,3,7,8-TCDD	2.4[a]	12	28			pg/g	rainbow trout	adult	food	approx 300 days	survival	reduced survival	Giesy et al. (2002)	LOAEL of 0.44 in fillet tissue measured at day 200 converted to concentration at approximately day 300 when mortality was observed based on recommendation from the author (Giesy 2006)
2,3,7,8-TCDD	46	85				pg/g	lake whitefish	juvenile	food	30 days	growth	body weight	Fisk et al. (1997)	exposed for 30 days and effect measured for 180 days post-exposure; unclear when residues measured; assumed WB residues, however liver tissue possibly excluded; 29% mortality in control
2,3,7,8-TCDD	87	102	2.56	34	40	pg/g	lake trout	egg (converted to adult WB)	water		reproduction (egg exposure)	sac-fry survival	Walker et al. (1994)	study measured through routes of exposure for the egg (maternal transfer, water, injection)–egg residues not statistically different based on exposure route; significant mortality observed at LOAEL; adult concentration was estimated using egg:adult conversion factor of 2.56 based on Tietge et. al. (1998)
2,3,7,8-TCDD	38	102	2.56	15	40	pg/g	lake trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	early life-stage survival	Spitsbergen et al. (1991)	22.5% cumulative mortality (egg, hatching, sac-fry) at LOAEL statistically significant; mortality at NOAEL (15.8%) not statistically different from control (18%); egg:adult conversion factor of 2.56 based on Tietge et. al. (1998)
2,3,7,8-TCDD	90	108	2.56	35	42	pg/g	lake trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	early life-stage survival	Guiney et al. (1996)	NOAEL and LOAEL (LC50) based on hatchery fish eggs; LOAEL is LC50; NOAEL and LC50 also reported in field-collected eggs (from Lake Ontario) and reference eggs (from Lake Ontario); Lake Ontario NOAEL=30-45 pg/g and LC50=44-72 pg/g; Lake Superior NOAEL=34 pg/g; egg:adult conversion factor of 2.56 based on Tietge et. al. (1998)
2,3,7,8-TCDD	59	128	2.56	23	50	pg/g	lake trout	egg (converted to adult WB)	maternal transfer	11 wks prior to spawning	reproduction (egg exposure)	sac-fry survival	Walker et al. (1994)	parental fish exposed via diet; study measured through routes of exposure for the egg (maternal transfer, water, injection)–egg residues not statistically different based on exposure route; significant mortality observed at LOAEL; mortality in control=7.2%; egg:adult conversion factor of 2.56 based on Tietge et. al. (1998)
2,3,7,8-TCDD	87	141	2.56	34	55	pg/g	lake trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	early life-stage and sac-fry survival	Walker et al. (1991); Walker et al. (1992)	statistically significant effects observed at LOAEL, frequency of sac-fry edema also statistically significant; LC50=65 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	72	150				pg/g	rainbow trout	juvenile	food	30 days	growth	body weight	Fisk et al. (1997)	exposed for 30 days and effect measured for 180 days post-exposure; unclear when residues measured; assumed WB residues, however liver tissue possibly excluded
2,3,7,8-TCDD	215	225	2.56	84	88	pg/g	brook trout	egg (converted to adult WB)	maternal transfer	throughout egg devl'p	reproduction (egg exposure)	swim-up and juvenile survival	Johnson et al. (1998)	parental fish (1.5 yr old) fed TCDD until spawning; LOAEL is calculated LC10; LC10 is less than residue at which mortality was observed (at 156 pg/g ww); NOAEL is egg residue where no significant mortality was observed; egg residues are approximate; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	346	474	2.56	135	185	pg/g	brook trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	sac-fry survival	Walker and Peterson (1994)	NOAEL and LOAEL as reported in study; at LOAEL 25% mortality; at NOAEL 10% mortality; egg:adult conversion factor of 2.56 based on Tietge et al. (1988);
2,3,7,8-TCDD	310	579	2.56	121	226	pg/g	lake trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	sac-fry growth (length), hatchability	Walker et al. (1991)	statistically significant effects observed at LOAEL; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
2,3,7,8-TCDD	448	691	2.56	175	270	pg/g	lake herring	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; six other fish species tested- lake herring was the most sensitive fish exposed to 2,3,7,8-TCDD; LC50=902 pg/g; LC10=509 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD		714	2.56		279	pg/g	rainbow trout	egg (converted to adult WB)	water	48 hrs	reproduction (egg exposure)	sac-fry survival	Walker et al. (1992)	LC50s also reported in study; sac-fry mortality most sensitive endpoint; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD		780				pg/g	rainbow trout	10-15cm	water	2 and 6 hrs	growth	body weight	Branson et al. (1985)	no statistics; LOAEL presented is based on tissue residues measured 28d after end of exposure, LOAEL is misleading; higher LOAEL should be used (max WB for dose, WB at end of exp, etc); tissue burdens assoc with same dose but measured earlier in exp were higher
2,3,7,8-TCDD		980				pg/g	rainbow trout	fry	water	~28 days	survival		Mehrle et al. (1988)	LOAEL is based on tissue residue measured at the end of the exposure period
2,3,7,8-TCDD		990				pg/g	rainbow trout	fry	water	~28 days	growth		Mehrle et al. (1988)	
2,3,7,8-TCDD	602	1,114	2.56	235	435	pg/g	fathead minnow	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=539 pg/g; LC10=293 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	1,486					pg/g	brook trout	adult	food	182 days	survival, growth, gonadal development, egg production		Tietge et al. (1998)	NOAEL is initial concentration in female fish exposed to 1,200 pg TCDD/g-food; Giesy et al. (2002) report adverse effects in rainbow trout at similar exposure levels after 250 days of exposure
2,3,7,8-TCDD		1,626	2.56		635	pg/g	killifish (mummi-chog)	egg (converted to adult WB)	water	through hatch or 30 days post-hatch	reproduction (egg exposure)	hatchability	Prince and Cooper (1995)	hatchability (61%); study compared the effects of TCDD-treated water on field-collected "non-impacted" eggs (from clean site - Tuckerton, NJ) and "impacted" eggs (from contaminated site - Newark Bay, NJ); no dose response from "impacted" eggs; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	125	2,170				pg/g	coho salmon	juvenile	water	96 hrs	growth		Miller et al. (1979)	body burdens measured after 114 days in clean water following exposure, thus not conservative
2,3,7,8-TCDD	125	2,170				pg/g	coho salmon	juvenile	water	96 hrs	survival		Miller et al. (1979)	body burdens measured after 114 days in clean water following exposure
2,3,7,8-TCDD	986	2,189	2.56	385	855	pg/g	channel catfish	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=644 pg/g; LC10=429 pg/g
2,3,7,8-TCDD		2,410				pg/g	medaka	juvenile	water	12 days	growth	body weight	Schmieder et al. (1995)	no statistics; growth increased 74% vs. 94% in control
2,3,7,8-TCDD	1,165	2,429	2.56	455	949	pg/g	medaka	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=1,110 pg/g; LC10=656 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	2,171	3,123	2.56	848	1,220	pg/g	white sucker	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=1,890 pg/g; LC10=1,590 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	3,046	4,608	2.56	1,190	1,800	pg/g	northern pike	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=2,460 pg/g; LC10=1,530 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)
2,3,7,8-TCDD	1,085	5,120	2.56	424	2,000	pg/g	zebra fish	egg (converted to adult WB)	water	100 days	reproduction (egg exposure)	early life-stage growth and survival	Elonen et al. (1998); Spehar et al. (1997)	statistically significant effects observed at LOAEL; LC50=2,610 pg/g; LC10=1,610 pg/g; egg:adult conversion factor of 2.56 based on Tietge et al. (1988)

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
2,3,7,8-TCDD		69,000				pg/g	fathead minnow	juvenile	water	28 day	survival		Adams et al. (1986)	no statistics—100% mort; LOAEL is average concentration in dead fish
2,3,7,8-TCDD	1,570	1,380,000				pg/g	rainbow trout	young	food	105 days	survival		Hawkes and Norris (1977)	
2,3,7,8-TCDD	1,570	1,380,000				pg/g	rainbow trout	young	food	105 days	growth	body weight	Hawkes and Norris (1977)	
PCBs (Aroclor 1260)		520				µg/kg	common barbel	adult	food	50 days	reproduction	fecundity	Hugla and Thome (1999)	Fecundity effect was not dose-responsive; number of fish tested unclear; uncertain statistical significance of fecundity endpoint; ww concentration converted from dw assuming 20% solids
PCBs (Aroclor mixture)					857	µg/kg	Atlantic salmon	embryo	water	48 hrs	reproduction (egg exposure)	live fry body weight	Fisher et al. (1994)	no effect on reproduction were observed
PCBs (Aroclor 1254)	980					µg/kg	chinook salmon	juvenile	food	4 wks	growth, survival		Powell et al. (2003)	whole body burdens ranged from 740 to 980 µg/kg ww over the 13-day period following treatment; only no-effect level reported; no effect on growth, survival, or survival following immunological challenge
PCBs (Aroclor 1254; egg)[a]					1,640	µg/kg	rainbow trout	egg	maternal transfer	60 days	reproduction (egg exposure)	fry growth	Hendricks et al. (1981)	eggs were exposed via maternal transfer from single gravid female fed 200 µg/g PCBs for 60 days
PCBs (Aroclor 1260)		2,640				µg/kg	common barbel	adult	food	75 days	reproduction	lack of spawning in first reproductive season; egg and larval mortality; fecundity	Hugla and Thome (1999)	fecundity effect was not dose-responsive; number of fish tested unclear; uncertain statistical significance of fecundity endpoint; ww concentration converted from dw assuming 20% solids
PCBs (Aroclor 1254)					3,200	µg/kg	Atlantic croaker	egg	maternal transfer	2 wks during reproduction (adults)	reproduction (egg exposure)	reduction in larval growth rate	McCarthy et al. (2003)	parental fish fed dietary PCBs, eggs exposed via maternal transfer; residues not clearly presented
PCBs (Aroclor 1254)	8,000					µg/kg	rainbow trout	14 wks	food	32 wks	growth, survival		Lieb et al. (1974)	only no-effect level reported
PCBs (Aroclor 1254)	1,900	9,300				µg/kg	sheepshead minnow	adult		28 days	reproduction	decreased fry survival	Hansen et al. (1974a)	elevated PCB concentrations in control fish; egg production was artificially stimulated by injecting the fish with human chorionic gonadotropic hormone
PCBs (Aroclor 1268)	15,000					µg/kg	mummichog	adult	food	~6 wks	reproduction	fertilization and hatching success, larval survival	Matta et al. (2001)	two generations of progeny observed; only no-effect level reported; offspring weight was significantly greater for PCB-exposed fish with parental tissue burdens equal to or greater than 1,300 µg/kg ww; however, this was not considered an adverse effect
PCBs (Aroclor 1254)	27,000	46,000				µg/kg	spot		water	20 days	survival		Hansen et al. (1971)	mortality did not appear directly related to body burden; bb increased with exposure duration; NOAEL (catfish) = 32
PCBs (Aroclor 1254)	31,000	71,000				µg/kg	brook trout	fry- exposure to eggs	water	10 days prior to hatch and 118 days after hatch	growth	reduced growth	Mauck et al. (1978)	residue measured at 118 days but was absent at 118 days.
PCBs (Aroclor 1254)					77,900	µg/kg	brook trout	egg	water	21 days	reproduction (egg exposure)	reduced hatchability	Freeman and Idler (1975)	75% hatching at LOAEL and 92% hatching in control; concentration in back muscle of dose fish with affected hatchability was 32.8 mg/kg ww
PCBs (Aroclor 1016)	110,000					µg/kg	sheepshead minnow	fry	water	4 wks	reproduction	fertilization and hatching success, larval survival	Hansen et al. (1975)	intermittent-flow toxicity test; no effect: fertilization success, survival of embryos to hatching, or survival of fry; only no-effect level reported; Juvenile tissue concentration LOAEL for reduced survival at the same exposure level was 220,000 µg/kg ww

Table 2, continued

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
PCBs (Aroclor 1016)		106,000				µg/kg	pinfish		water	33 days	survival, behavior	loss of equilibrium; erratic swimming	Hansen et al. (1974b)	significant reduction in survival (50% mortality relative to 6% in control)
PCBs (Aroclor 1254:1260 mixture)	120,000					µg/kg	rainbow trout	young	water	90 days	survival		Mayer et al. (1985)	mortality observed; not significantly different; dose was 1:2 ratio of Aroclor 1254:1260; only no-effect level reported
PCBs (Aroclor 1254:1260 mixture)	70,000	120,000				µg/kg	rainbow trout	young	water	90 days	growth		Mayer et al. (1985)	
PCBs (Aroclor 1254)	71,000	125,000				µg/kg	brook trout	fry- exposure to eggs	water	10days prior to hatch and 118days after hatch	survival	fry survival	Mauck et al. (1978)	reduced fry survival; 21 to 100% mortality; tissue residue measured at 118 days; Median hatching time and egg hatchability were not affected; larval growth was initially reduced, but not by the end of the test
PCBs (Aroclor 1016)	57,000	200,000				µg/kg	sheepshead minnow	fry	water		survival	fry survival	Hansen et al. (1975)	
PCBs (Clophen A50)		250,000				µg/kg	goldfish		water	5-21 days	survival	survival	Hattula and Karlog (1972)	LOAEL is concentration in individual dead fish
PCBs (Aroclor 1254)		429,000 (female)				µg/kg	fathead minnow		water		reproduction	reduced spawning	Nebeker et al. (1974)	mean terminal residue; egg hatchability and fry survival was not affected
PCBs (Aroclor 1242, 1254, or 1260)		1,860 – 749,000				µg/kg	fathead minnow		water	up to 300 hrs	survival	lethal body burden	van Wezel et al. (1995)	Tissue concentrations of individual fish that died in less than 20 hours ranged from 1,800 to 30,000 µg/kg ww; tissue concentrations of individual fish that died at 100 to 300 hours ranged from 120,000 to 749,000 µg/kg ww.
Mercury (mercuric chloride)	0.2					mg/kg	guppy	male adult	sediment and water	20 days	survival		Kudo and Mortimer (1979)	only no-effect level reported
Mercury					14	µg/kg	catfish	4 days post-hatch	water	spawning until 4 d post-hatch	survival	67% survival	Birge et al. (1979)	LOAEL is sac-fry concentration at 4 days post-hatch; control data was not reported; 17% survival was reported in catfish with WB residues of 1.15 µg/g ww
Mercury (inorganic Hg)					36	µg/kg	rainbow trout	alevins	exposed to contamin-ated sediment	20 days	reproduction (egg exposure)	egg/embryo survival reduced by 46%	Birge et al. (1979)	LOAEL is based on alevin (sac-fry) concentration of 0.036; adult concentration was estimated using sac-fry:adult conversion factor of 64.4 based on rainbow trout data from Niimi (1983) and assuming 3:2 ratio of concentration of sac-fry:egg
Mercury					41	µg/kg	rainbow trout	4 days post-hatch	water	spawning until 4 days post-hatch	survival	45% survival	Birge et al. (1979)	LOAEL is sac-fry concentration at 4 days post-hatch; 94% survival was reported in controls; 39 - 79% survival was reported in eggs with concentrations of 0.0682 µg/g ww; adult concentration was estimated using sac-fry:adult conversion factor of 64.4 based on rainbow trout data from Niimi (1983) and assuming 3:2 ratio of concentration of sac-fry:egg
Mercury (methylmercury)	230					µg/kg	golden shiner		food	90 days	survival	predator avoidance	Webber and Haines (2003)	Field collected fish (but from a manmade cement lined pond). Predator avoidance was reduced at this NOAEL; growth accompanied by reduced feeding was reduced at NOAEL but not dose-responsive, no effect on growth was observed in fish fed 959 ng/g ww where WB residue = 518 ug/g ww
Mercury (methyl-mercuric chloride)	200	470				µg/kg	mummichog	adult	water	42 days	survival		Matta et al. (2001)	effects observed in male fish but not females
Mercury (methylmercury)				990		µg/kg	walleye (field-collected)	egg	maternal transfer		reproduction (egg exposure)	fertilization and hatching success, larval length	Latif et al. (2001)	field-collected fish; adult concentration was estimated using egg:adult conversion factor of 36.05 based on average data reported in five species in Niimi (1983); mercury concentrations of diet not reported
Mercury (mercuric chloride)	0.8	1,310				µg/kg	fathead minnow	3 mos	food	60 days	growth		Snarski and Olson (1982)	

Table 2, continued

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Mercury (methyl-mercuric chloride)	2,280					µg/kg	rainbow trout	fingerling	water	24 days	growth		Phillips and Buhler (1978)	only no-effect level reported
Mercury (methylmercury)	2,700	3,400				µg/kg	brook trout	embryo – adult	water	756 days	reproduction	reduced number of viable eggs produced	McKim et al. (1976)	residue measured in parental fish at 39 weeks; NOAEL is recommended no effect level presented in study (for abnormalities and multigenerational mortalities); NOAEL based on the data for no effect on the number of viable eggs produced was 1.1 µg/g ww
Mercury (methylmercury)					3,800	µg/kg	grayling	sac-fry (converted to adult WB)	water	1st 10 days of develop-ment	survival	increased fry mortality	Fjeld et al. (1998)	NOAEL and LOAEL reported as yolk-fry concentration; adult concentration was estimated using sac-fry:adult conversion factor of 64.4 based on rainbow trout data from Niimi (1983) and assuming 3:2 ratio of concentration of sac-fry:egg
Mercury (mercuric chloride)	2,750	4,180				µg/kg	fathead minnow	3 month old	water	60 days	survival		Snarski and Olson (1982)	
Mercury (mercuric chloride)	2,840	4,470				µg/kg	fathead minnow	larvae-adult	water	287 days	reproduction		Snarski and Olson (1982)	
Mercury (methylmercury)	5,000					µg/kg	rainbow trout	juvenile	water	84 days	growth, survival		Lock (1975)	only no-effect level reported
Mercury (mercuric chloride)		5,600				µg/kg	goldfish	4.5-6.5 cm	water	2 days	survival		Heisinger et al. (1979)	Concentration converted from dry weight to wet weight assuming 80% moisture in whole fish
Mercury (methyl-mercuric chloride)	5,670					µg/kg	rainbow trout	fingerling	water	24 days	growth		Phillips and Buhler (1978)	only no-effect level reported
Mercury (methyl-mercuric chloride)		6,500				µg/kg	bluegill	juvenile	water	12.5 days	survival		Cember et al. 1978	
Mercury (methyl-mercuric chloride)	8,630					µg/kg	rainbow trout	fingerling	water	24 days	growth		Phillips and Buhler (1978)	brook trout = 9.4 (NOAEL); only no-effect level reported
Mercury	9,400					µg/kg	brook trout	39 wks old	water	756 days	growth, survival	reduced juvenile weight	McKim et al. (1976)	residues measured in parental fish at 39 weeks; only no-effect level reported
Mercury (methylmercury)		10,000				µg/kg	rainbow trout	fingerling	food	84 days	growth	reduced growth and final body weight (after 84 days)	Rodgers and Beamish (1982)	reduced growth associated with feeding; approximated from graph (and text); at 14 days of treatment Hg concentrations in WB tissues were lower (approx. 5 µg/g ww); however, effects were observed (and significant) over the 84 days of exposure
Mercury (methylmercury)	10,900					µg/kg	fathead minnow	larvae-adult	water	336 days	growth, survival		Olson et al. (1975)	only no-effect level reported
Mercury (methyl-mercuric chloride)	1,100	11,000				µg/kg	mummichog		food	42 days	reproduction	F1 fertilization success	Matta et al. (2001)	residue measured in parental fish
Mercury (methyl-mercuric chloride)	12,000					µg/kg	rainbow trout	sub-adult	water	75 days	growth, survival	body weight	Niimi and Lowe-Jinde (1984)	only no-effect level reported
Mercury (methyl-mercuric chloride)	12,000					µg/kg	mummichog		food	42 days	reproduction	F1 hatchability, survival, fecundity, F2 larval survival	Matta et al. (2001)	residue measured in female parental fish; only no-effect level reported
Mercury (methyl-mercuric chloride)	12,000					µg/kg	mummichog		food	42 days	reproduction	fecundity, fertilization success, offspring weight, female survival	Matta et al. (2001)	offspring of medium and high doses were larger than offspring of control fish; only no-effect level reported; residue measured in female parental fish
Mercury	29,000					µg/kg	rainbow trout	fingerling		84 days	survival		Rodgers and Beamish (1982)	only no-effect level reported

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Mercury (methylmercury)				16,000	29,000	µg/kg	Japanese medaka	egg (converted to adult WB)	water	16 days	reproduction (egg exposure)	hatchability	Heisinger and Green (1975)	at LOAEL - 20.8% hatchability; at NOAEL - 58.3% hatchability; at control - 46.7% hatchability; adult concentration was estimated using egg:adult conversion factor of 36.05 based on average data reported in five species in Niimi (1983)
Selenium	1,200	1,600				µg/kg	National criteria	na	na	na	protection of aquatic life	chronic criteria	EPA (2004)	concentration converted to ww assuming 80% moisture content;
TBT	18	159				µg/kg	Japanese flounder	larvae	food	approx 65 days	growth	body weight	Shimasaki et al. (2003)	all test fish were genetically XX fish by parents both XX but one parent phenotypically male and functional; No replication in study; survival was not significantly affected at any dose; mortality was observed in all groups, including the control group.
TBT		1,054				µg/kg	Japanese medaka	adult	food	3 wks	reproduction	reduced swim-up failure	Nakayama et al. (2005)	LOAEL is concentration in adult female fish using an adult:egg conversion factor of 8.57 based on Nirmala et al. (1999); effects were observed in offspring; concentration in egg tissues was 123 µg/kg
TBT		2,390				µg/kg	Japanese medaka	adult	food	3 wks	reproduction	reduced hatching success, swim-up success, and embryonic success	Nirmala et al. (1999)	LOAEL is concentration in adult female fish; effects were observed in offspring
Chlordane (alpha-chlordane and gamma-chlordane)	190 - 710					µg/kg	goldfish		food and water	96 hrs	survival	survival	Moore et al. (1977)	uncontrolled study; NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported
Chlordane (cis-chlordane)		1,360				µg/kg	goldfish		water	24 hrs	survival	survival 3/9 fish died	Feroz and Khan (1979)	uncontrolled study; no clear residue burden and response to mortality effects; LOAEL is based on residues in carcasses of 3 dead fish; surviving fish tissue residues were 2.9 µg/g ww (at 10 days after exposure) and 2.1 µg/g (at 25 days after exposure)
Chlordane (tech chlordane)		16,600				µg/kg	pinfish	fry/ juvenile	water	96 hrs	survival	30% mortality	Parrish et al. (1976)	96-hr exposure; tissue residues in surviving fish exposed to 5.4 µg/L aqueous chlordane; seawater
Chlordane (tech chlordane)	87,000					µg/kg	sheepshead minnow	fry/juvenile	water	28 day	survival	3.7% mortality	Parrish et al. (1976)	28-day embryo/fry exposure; tissue residues in surviving fish exposed to 7.1 µg/L; tissue residues not reported in fish exposed to higher aqueous concentrations (100% mortality); seawater
Chlordane (tech chlordane)		281,000				µg/kg	sheepshead minnow	fry/juvenile	water	96 hrs	survival	25% mortality	Parrish et al. (1976)	96-hr exposure; tissue residues in surviving fish exposed to 15 µg/L; seawater; tissue residue concentration at lowest water treated concentration (unbounded)
DDT (mixture)	25					µg/kg	golden shiner		food	6-15 days	survival	survival	Courtney and Reed (1971)	converted from dry weight to wet weight using factor given in paper
DDT (mixture)		550				µg/kg	pinfish	4.8 g	diet	15 days	survival	44% mortality at 10 days	Butler (1969)	4% mortality in control; residues were much higher in live fish (LOAEL is residue of dead fish); at 7 days live fish WB residue = 2,700 µg/kg ww; residues were 640 µg/kg ww where morality was 10% (at 14 days); poorly reported study; no clear dose-response
DDT (mixture)	1,800	1,800				µg/kg	cutthroat trout	21 months	water	612 days (mortality observed at 111 days)	survival		Allison et al. (1964)	LOAEL is tissue concentration at 111 days (3.7 months) in fish exposed to 0.1 mg/kg DDT in water where mortality was significant after "4 months" (approximately 120d), note that tissue concentrations at this dose increased to 3.0 mg/kg at the next sampling
DDT (total)	1,920					µg/kg	brook trout	juvenile		120 days	survival		Macek and Korn (1970)	no effect level reported

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
DDT (total)	1,200	2,000				µg/kg	cutthroat trout	yearlings	water	20 mo (mortality observed at 4 mo)	survival	survival	Allison et al. (1963)	LOAEL is tissue concentration at 56 days (1.9 months) in fish exposed to 1.0 mg/kg DDT in water where mortality was significant after "4 months" (approximately 120d), note that tissue concentrations at this dose increased to 4,300 µg/kg at the next sampling.
DDT (total)		2,800 - 3,000				µg/kg	brook trout	sex mat yearlings	food	156 days	reproduction	offspring (sac-fry and embryo) mortality	Macek (1968b)	LOAEL is range of parental tissue residues; residues in offspring (fry) ranged from 2,620 to 3,090 µg/kg ww
DDT (total)	620	3,650				µg/kg	chinook salmon	0.61g	food	40 days	survival		Buhler et al. (1969)	tissue concentration at 4 and 7 days; growth increase attributed to size -selective mortality
DDT (total)	4,670					µg/kg	rainbow trout	15 g	food	140 days	growth, survival	survival, growth	Macek et al. (1970)	no effect level reported
DDT (total)		5,200				µg/kg	killifish		water	24 hrs	survival	25% mortality at 24 hrs	Crawford and Guarino (1976)	LOAEL is the weighted sum of residues in 10 different tissues of fish exposed to 0.1 ppm DDT for two 24hr DDT doses at 24 hrs after exposures; at 8 days after exposures, weighted sum of residues was 3,900 µg/kg ww, however, mortality started occurring at 24 hours.
DDT (mixture)	3,900	5,500				µg/kg	cutthroat trout	21 month old	food	612 days	survival	survival	Allison et al. (1964)	control diet had 760 µg/kg DDT; LOAEL tissue residue measured at day 166 in fish fed to 1,000 µg/kg body weight (bw) DDT and where mortality was observed; NOAEL is highest tissue concentration in fish fed 300 µg/kg bw DDT where significant mortality was not observed over entire exposure duration of 20 months; concentration is total chlorinated hydrocarbons
DDT (mixture)		5,600				µg/kg	pinfish	3.0 g	food	21 days	survival	35% mortality at 21 days	Butler (1969)	0% mortality in control; LOAEL is residue of dead fish; residues were 3,300 µg/kg ww where morality was 10% (at 14 days); poorly reported study; no clear dose-response of tissues with mortality across the experiments presented in the paper
DDT (mixture)		7,890				µg/kg	pinfish	3.0 g	food	2 days	survival	63.5% mortality	Butler (1969)	0% mortality in control; LOAEL is residue of dead fish; poorly reported study; no clear dose-response of tissues with mortality across the experiments presented in the paper
DDT (total)	7,600					µg/kg	brook trout fry	fry	food	156 days	growth, survival	survival, growth	Macek (1968b)	other fish species from study not reported because NOAEL/LOAELs are much higher; no effect level reported; length but not weight of male fish was significantly greater than controls
DDT (total)	11,200					µg/kg	brook trout	under yearling	food	31 wks	growth	increased growth	Macek (1968a)	NOAEL effect is an increase in growth (significant); sum of DDD, DDE, and DDT concentrations
DDT (total)	11,400	12,100				µg/kg	chinook salmon	1.1 g	food	40 days	survival	survival	Buhler et al. (1969)	tissues sampled at 4 and 7 days
DDT (total)		20,200 - 45,800				µg/kg	brook trout	under yearling	food	26 wks	survival	reduced survival during stress (starvation)	Macek (1968a)	sum of DDD, DDE, 2,4'-DDT and 4,4'-DDT in fish exposed to 2.0 mg/kg/wk DDT
DDT (total)		24,000				µg/kg	green sunfish/ pumpkin-- seed		water	90 days	survival	survival	Hamelink et al. (1971)	
DDT (mixture)	24,000					µg/kg	Atlantic menhaden		food	48 (109)[a]	growth	growth	Warlen et al. (1977)	fish exposed for 48 days and observed for 109 days after exposure; no effect level reported
DDT (total)		26,500				µg/kg	mosquito fish		water	16 days	survival	survival	Pillai et al. (1977)	
DDT (total)	40,000					µg/kg	fathead minnow	juvenile-adult		266 days	survival	survival	Jarvinen et al. (1976; 1977)	no effect level reported

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
DDT (total)	51,400	92,700				µg/kg	sailfin molly		water	21 days	growth, survival	survival, growth	Benton et al. (1994)	converted from dry weight to wet weight based on reported 24% solids; sum of 2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD
DDT (total)	16,600	69,600				µg/kg	coho salmon	3.7 g	food	60 days	survival	survival	Buhler et al. (1969)	tissues sampled at 4 and 7 days
DDT (total)	130,000					µg/kg	goldfish	9.1 g	food and water	58 days	survival	survival	Rhead and Perkins (1984)	converted from dry weight to wet weight assuming 20% solids; no effect level reported
DDT (total)		200,000				µg/kg	goldfish	9.1 g	food and water	38 days	survival	survival	Rhead and Perkins (1984)	converted from dry weight to wet weight assuming 20% solids
Dieldrin	85 - 120					µg/kg	largemouth bass	adult	food	30-50 days	survival, growth	body weight, length, condition factor, survival	Muller et al. (2004)	estimated from graph; not clear if gonads included (measured at 1-3.5% of whole body concentration); blood not included
Dieldrin	120	200				µg/kg	rainbow trout	juvenile	food and water	16 wks	survival	33% mortality	Shubat and Curtis (1986)	5 of 15 fish died in high treated water (no maintenance diet treatment) and 4 of 15 fish died in high treated water and maintenance treated diet; no statistics; assumed no mortalities in control; no replication
Dieldrin	1,400					µg/kg	rainbow trout	juvenile		16 wks	growth		Shubat and Curtis (1986)	highest residue concentration in growth diet group (maintenance diet group with residues up to 0.36 ppm); no effect observed in body weight of treated fish groups
Endosulfan (tech endosulfan (sum of endosulfan I, II, and endosulfan sulfate)	3.1[b]	31				µg/kg	spot		water	96 hrs	survival	35% mortality; 10% mortality (control)	Schimmel et al. (1977a)	tissue residues of surviving fish
Endosulfan (tech endosulfan (sum of endosulfan I, II, and endosulfan sulfate)	195	272				µg/kg	pinfish		water	96 hrs	survival	35% mortality LOAEL; 5% NOAEL	Schimmel et al. (1977a)	tissue residues of surviving fish
Endosulfan (tech endosulfan (sum of endosulfan I, II, and endosulfan sulfate)		360				µg/kg	mullet		water	96 hrs	survival	40% mort; 0% mortality (control)	Schimmel et al. (1977a)	tissue residues of surviving fish
Endrin (technical endrin)	1.15[b]	11.5				µg/kg	largemouth bass	fingerlings	water	20 days	survival	40% fingerling mortality	Fabacher (1976)	one dose; no statistics; static tanks treated every 5 days; residues in dead fish
Endrin (analytical endrin)		240				µg/kg	fathead minnow	30d	food and water	300 days (also reprod period)	survival		Jarvinen and Tyo (1978)	statistically significant results at LOAEL
Endrin	307					µg/kg	channel catfish	fingerlings	food	198 days	survival		Argyle et al. (1973)	no statistics; only no-effect level reported
Endrin	307					µg/kg	channel catfish	fingerlings	food	198 days	growth		Argyle et al. (1973)	no statistics; only no-effect level reported; LOAEL is average residue from day 20 to day 198
Endrin	410	720				µg/kg	channel catfish	fingerlings	water	55 days	survival		Argyle et al. (1973)	no statistics - 40% mortality; LOAEL is concentration at day 26 when mortality began; NOAEL is mean concentration when residue levels were maximal from days 49-55
Endrin	110	880				µg/kg	sheepshead minnow	all	water	4 wks	survival	juvenile survival-1 month survival of F2	Hansen et al. (1977)	saltwater species, embryos spawned from field-collected adults; tissue residues in juvenile fish- effects based on mortality effects in fry
Endrin	260	940				µg/kg	sheepshead minnow	all	water	2 generations	reproduction	female fertility	Hansen et al. (1977)	saltwater species, embryos spawned from field-collected adults
Endrin		1,660				µg/kg	golden shiner		water	8 hrs	survival	100% mortality	Ludke et al. (1968)	LOAEL is average residue at time of death; average residue over 8 hours = 0.97 mg/kg ww (resistant [i.e. pre-exposed] test fish not evaluated)

Table 2, continued

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
gamma-Hexachloro-cyclohexane (lindane)	1,580[c]	79,000				µg/kg	sheepshead minnow	17-21 mm			survival	LR50	Schimmel et al. (1977b)	LR50
Heptachlor (tech heptachlor: 65% heptachlor; 22% trans-chlordane; 2% cis-chlordane; 2% nonachlor)	150[b]	1,500				µg/kg	spot		water	96 hrs	survival	LOAEL- 25% mortality	Schimmel et al. (1976)	no statistical methods; saltwater study
Heptachlor (technical heptachlor)		1,900 - 2,600				µg/kg	bluegill		food	up to 140 days	growth	average body weight	Andrews et al. (1966)	fish were exposed to 5 ppm technical heptachlor; growth effects were not statistically evaluated; LOAEL is range of heptachlor residue concentrations (in two replicates) where average body weight was reduced (approx 90% of controls) after 28 days; growth e
Heptachlor	1,700	5,300				µg/kg	spot		water	96 hrs	survival	NOAEL-0% mortality; LOAEL 85% mortality	Schimmel et al. (1976)	no statistical methods; saltwater study
Heptachlor (technical heptachlor)		17,300 - 24,800				µg/kg			water	24 hrs	survival	90% mortality	Andrews et al. (1966)	fish were exposed to technical heptachlor; 90% mortality was observed after 72 hrs following exposure period in fish exposed to 0.0500 and 0.0375 ppm technical heptachlor; LOAEL is tissue residues at these dose levels at 72 hrs; heptachlor epoxide, other related compounds and DDT were also measured in fish tissue
Heptachlor		20,000				µg/kg	sheepshead minnow		water	96 hrs	survival	LOAEL- 35% mortality	Schimmel et al. (1976)	no statistical methods; saltwater study
Heptachlor (tech heptachlor: 65% heptachlor; 22% trans-chlordane; 2% cis-chlordane; 2% nonachlor)\	5,700	34,000				µg/kg	pinfish		water	96 hrs	survival	NOAEL-5% mortality; LOAEL-50% mortality	Schimmel et al. (1976)	no statistical methods; saltwater study
Heptachlor epoxide (tech heptachlor)	80[b]	800 - 900				µg/kg	bluegill		food	up to 140 days	growth	average body weight	Andrews et al. (1966)	fish were exposed to 5 ppm technical heptachlor; growth effects were not statistically evaluated; LOAEL is range of heptachlor residue concentrations (in two replicates) where average body weight was reduced (approx 90% of controls) after 28 days; growth effects were more pronounced at higher dose levels and after greater exposure duration; heptachlor, other related compounds and DDT were also measured in fish tissue
Heptachlor epoxide (tech heptachlor)		1,660 - 2,400				µg/kg	bluegill		water	24 hrs	survival	90% mortality	Andrews et al. (1966)	fish were exposed to technical heptachlor; 90% mortality was observed after 72 hrs following exposure period in fish exposed to 50 and 37.5 µg/kg technical heptachlor; LOAEL is tissue residues at these dose levels at 72 hrs; heptachlor, other related compounds and DDT were also measured in fish tissue
Hexachlorobenzene	46,500					µg/kg	fathead minnow		water	28-day exposure	survival		Nebeker et al. (1989)	
Hexachlorobenzene	46,500					µg/kg	fathead minnow		water	28-day exposure	growth		Nebeker et al. (1989)	
Hexachlorobenzene	97,000					µg/kg	fathead minnow	embryo - juvenile	water	32 days	growth, survival	final body weight, survival	Carlson and Kosian (1987)	no significant effect on growth or survival
Hexachlorobenzene	97,000					µg/kg	fathead minnow	embryo	water	32-day exposure	growth, survival		Carlson and Kosian (1987)	development/mortality; embryos 4-12 hrs old; exposure period during embryo-to-juvenile stage; NOAEL is mean tissue residue n=2

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Hexachlorobenzene	282,000					µg/kg	fathead minnow		sediment and water	28-day exposure	survival		Schuytema et al. (1990)	exposure period followed by 15-28 day depuration; uptake/bioaccumulation study
Hexachlorobenzene	468,000					µg/kg	fathead minnow		water	28-day exposure	survival		Schuytema et al. (1990)	exposure period followed by 15-28 day depuration; uptake/bioaccumulation study
Methoxychlor	50	300				µg/kg	brook trout	yearlings	food	30 days	growth	body weight	Oladimeji and Leduc (1975)	fish were fed four different concentrations of methoxychlor at four different rates resulting in the same dose of 0.67 mg/kg bw/d; LOAEL is WB concentration in fish fed at 1% ingestion rate
4-methylphenol	1,530[c]	76,500				µg/kg	rainbow trout		injection	96 hrs	survival	LD50	Kaiser et al. (1984)	LOAEL is injected LD50 dose following 96-hr exposure; tissue residues not measured
4-methylphenol		78,900				µg/kg	rainbow trout		injection	96 hrs	survival	LD50	Hodson et al. (1988)	LOAEL is injected LD50 dose following 96-hr exposure
Phenol	1,470[c]	73,400				µg/kg	rainbow trout		water	13 hrs	survival	lethal body burden	McKim & Schmieder (1990)	LOAEL is reported lethal residue - limited detail on study methods
Phenol	76,000	114,000				µg/kg	goldfish		water	25 hrs	survival	LC50	Kobayashi et al. (1979)	LOAEL is LC50 body burden based on dead fish exposed to 60 µg/L; NOAEL is estimated body burden using BCF reported in study (1.9) and water concentration (40 µg/L) where 95% survival was reported over the duration of the experiment
Phenol		238,000				µg/kg	goldfish		water	5 hrs	survival	LC50	Kishino and Kobayashi (1995)	LOAEL is LC 50 from pH 8 study; LC50s were 273, 238, and 420 µg/g at pH 6, 8 and 10, respectively; mean residues of dead fish from all exposure levels from pH levels 6-10 were: 223 - 309 µg/g
Phenol		420,000				µg/kg	rainbow trout		injection	96 hrs	survival	LD50	Kaiser et al. (1984)	LOAEL is injected LD50 dose following 96-hr exposure; tissue residues not measured
Bis (2-ethylhexyl) phthalate	390					µg/kg	rainbow trout - sac fry			10 day prior to hatch and effects measured 24 days post hatch	reproduction (sac-fry survival)	13% mortality at NOAEL (not statistically different than control); 6% mortality in control	Mehrle and Mayer (1976)	fry tissue residues calculated from bioconcentration factor and water concentrations reported in paper.
Bis (2-ethylhexyl) phthalate	1,000 - 6,750					µg/kg	sheepshead minnow		water	24 hrs	survival	survival	Wofford et al. (1981)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported
Butylbenzyl phthalate	6,450					µg/kg	bluegill		water	21 days	survival	survival	Barrows et al. (1980)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported; study is a bioaccumulation study
Di(n)butyl phthalate	660					µg/kg	bluegill		water	42 days	survival	survival	Barrows et al. (1980)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported; study is a bioaccumulation study
Di(n)butyl phthalate	1,170					µg/kg	sheepshead minnow		water	24 hrs	survival	survival	Wofford et al. (1981)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported
Dimethyl phthalate	498					µg/kg	bluegill		water	21 days	survival	survival	Barrows et al. (1980)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported; study is a bioaccumulation study
Diethyl phthalate	1,102					µg/kg	bluegill		water	21 days	survival	survival	Barrows et al. (1980)	NOAEL is based on assumed 100% survival; NOAEL is based on the assumption that no mortality was observed because none was reported; study is a bioaccumulation study

Chemical	NOAEL (WB)	LOAEL (WB)	Conv. Factor	NOAEL (egg)	LOAEL (egg)	Unit (ww)	Test Species	Lifestage	Exposure Mode	Exposure Duration	Endpoint	Endpoint Effect	Source	Notes
Benzoic acid	3,380					µg/kg	mosquito fish		water	24 hrs	survival	survival	Lu and Metcalf (1975)	highly uncertain study- exposure conditions was a mini-ecosystem with no mortality results discussed (bioaccumulation study); was assumed that no mortality was observed because none was reported

[a] NOAEL estimated using uncertainty factor of 5 (chronic LOAEL to chronic NOAEL).

[b] NOAEL estimated using uncertainty factor of 10 (acute LOAEL to chronic NOAEL).

[c] NOAEL estimated using uncertainty factor of 50 (LC50 to chronic NOAEL).

LC10 – concentration that causes the death of 10% of a group of test animals

LC50 – concentration that causes the death of 50% of a group of test animals

LOAEL – lowest-observed-adverse-effect level

NC – TRVs not reported in database because study only injection dose was reported (no WB tissue residues were reported)

NOAEL – no-observed-adverse-effect level

PCB – polychlorinated biphenyl

TCDD – tetrachlorodibenzo-*p*-dioxin

TBT – tributyltin

ww – concentration in fish tissue was reported on a wet weight basis

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