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EFFECTS OF SUSPENDED SEDIMENTS ON SALMONIDS

Bachman, R.A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Brown trout in a stream ceased to feed in turbidities of 35 ppm.

Barrett, J.C., G.D. Grossman, and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 4:437-443.

Feeding trials were conducted on rainbow trout at three levels of suspended sediment to determine the effects of turbidity on reactive distance and pursuit speed. Reactive distances in the 15-30 NTU (nephelometric turbidity unit) treatments were only 45% to 80% of those observed at ambient turbidities (4-6 NTUs). No significant effects on pursuit speed were found.

Berg, L., and T.G. Northcote. 1985. Changes in territorial, gill-flaring and feeding behaviour in juvenile coho salmon (Oncorhynchus kisutch) following short-term pulses of suspended sediment. Canadian Journal of Fisheries and Aquatic Sciences 42:1410-1417.

Found cough frequency was significantly elevated when subyearling coho were exposed to suspended sediments (gravel pit fines, 0.02-0.06 mm) for 1-48 hours at 30 NTU.

Billard, R. 1982. Influence of clay sediments suspended in insemination diluent on the fertilization of the eggs of trout (Salmo gairdneri). Water Research 16:725-728.

Trout eggs were exposed for 1 to 20 minutes to suspended clay sediments before fertilization, or fertilized in an artificial insemination diluent containing suspended Kaolinite-rich clay. Fertilization rates declined when eggs were exposed to sediment exceeding 1.2 g/l for 10 minutes or longer. This is in French and only the abstract is available in English. (UW-Fisheries)

Bisson, P.A., and R.E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 4:371-374.

Reports a 13% decrease ($p < 0.05$) in numbers of native coho in the turbid side of a horizontal trough at 70 NTU. Displacement occurred as turbidity reached 50 NTU.

** **Emmett, R.L., G.T. McCabe, Jr., and W.D. Muir. Effects of the 1980 Mount St. Helens eruption on Columbia River estuarine fishes: implications for dredging in northwest estuaries. Pages 74-91 in C.A. Simenstad, editor. Effects of dredging on anadromous Pacific coast fishes workshop proceedings, September 8-9, 1988, Seattle, Washington. Washington Sea Grant Report WSG-WO-90-1, Seattle, Washington.**

Biological sampling of the estuary occurred prior to and after the eruption. Turbidities rose from 10-30 JTU to 1,500 within 3 days after the eruption. After the 1980 eruption, the distribution patterns of juvenile salmonids changed. Juvenile chinook became less abundant in open-water areas of the upper estuary and were more abundant in open-water areas of the central and lower estuary. All salmonid species showed an increase in the percentage of empty stomachs and prey species, such as amphipods, were also lower in abundance after the eruption.

Garric, J., B. Migeon, and E. Vindimian. 1990. Lethal effects of draining on brown trout. A predictive model based on field and laboratory studies. Water Research 24:59-65.

A field study (River Isere in France) and laboratory surveys of ecotoxicological hazards (increase in suspended solids and ammonia, and a decrease in oxygen) linked with dam draining were performed. The LT50 for brown trout exposed to 33 g/l of clay (< 2 μm) was 20.7 hours; and 10 hours for those exposed to sand (50-200 μm). (UW-Fisheries)

Gregory, R.S. 1994. The influence of ontogeny, perceived risk of predation, and visual ability on the foraging behavior of juvenile chinook salmon. Pages 271-284 in D.J. Stouder, K.L. Fresh, and R.J. Feller, editors. Theory and application in fish feeding ecology. Proceedings of GUTSHOP '92, The Belle W. Burach Library in Marine Science no. 18.

Juvenile chinook salmon had increased foraging rates on surface and benthic prey at 18-150 NTUs compared with < 1 NTU and 370-810 NTUs. Smaller individuals (49-55 mm FL) preferred foraging in clearer water than larger individuals (57-69 mm FL). Above 150 NTUs, juvenile chinook exhibit reduced feeding regardless of forager size. (USFWS-WWFRO)

Harvey, G.W. 1989. Technical review of sediment criteria. Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau, Boise, Idaho.

Sediment criteria for Idaho streams are provided. In waters with salmonid fisheries, turbidity is not to exceed background turbidity by 50 NTU instantaneously or 25 NTU for 10 days.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Management 7:34-45.

Authors conclude, after a review of studies, that water quality standards allowing increases of 5 to 25 NTUs above ambient turbidity in clear coldwater habitats provide relatively high and moderate protection, respectively, for salmonids in Alaska. An extensive table reporting effects of turbidity and suspended sediment concentrations on salmonids and a summary of turbidity standards for several states are provided.

Lloyd, D.S., J.P. Koenings, J.D. LaPierre. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.

A literature review on the effects of turbidity on coldwater systems and the relationships between suspended sediment concentration and resulting turbidity was reported. The following regression equation was developed for large silt-laden rivers: $T = 0.44(SSC)^{0.858}$, where T = turbidity (NTU) and SSC = suspended sediment concentration (mg/l). At 25-70 NTU the ability of salmonids to find and capture food is impaired.

Lucas, R.E. 1985. Recovery of game fish populations impacted by the May 18, 1980 eruption of Mount St. Helens. Washington Department of Game, Fishery Management Report 85-9A.

Juvenile fish were monitored for 4 years following Mt. St. Helens eruption. Juvenile salmonids moved out of the South fork mainstem, which experienced heavy sediment loading during summer snow melt 1 year after the eruption, to the mouths of clear tributaries. In 1980 many adults were found dead, full of milt and eggs. Significantly higher salmonid densities were found in unaffected stream sections in 1981 and large numbers of summer and winter steelhead strayed from the Toutle River to the Kalama and Lewis Rivers in 1981 and 1982. Flushing of fines from spawning gravel was rapid in watersheds with narrow floodplains.

Martin, D.J., E.O. Salo, and B.P. Snyder. 1977. Field bioassay studies on the tolerances of juvenile salmonids to various levels of suspended solids. University of Washington, Fisheries Research Institute, Technical Completion Report FRI-UW-7713.

Found the toxicity of suspended sediment to chum salmon to be a function of suspended sediment concentration and fish condition. The 96-hr LC10, LC50, and LC90 obtained for healthy salmon were 241, 1047, and 4611 mg/L, respectively. The calculated 96-hr LC10, LC50, and LC90 for diseased salmon (vibriosis) were 8-45, 81-415, and 769-3810 mg/L, respectively.

McCrimmon, H.R. 1954. Stream studies on planted Atlantic salmon. Journal of the Fisheries Research Board of Canada 11(4):362-403.

Survival and distribution of Atlantic salmon fry planted in a tributary to Lake Ontario were evaluated. No appreciable effects of turbidities up to 1150 ppm on Atlantic salmon parr were found. Young salmon were found to require spaces around gravel for shelter. Survival of planted underyearlings in unsedimented areas was 23.4%, while only 2.2% survived in areas where sedimentation was the heaviest.

Newcomb, T.W., and T.A. Flagg. 1983. Some effects of Mt. St. Helens volcanic ash on juvenile salmon smolts. Marine Fisheries Review 45(2):8-12.

Reported a 36-hr LC50 for sockeye salmon smolts exposed to Mt. St. Helens volcanic ash to be 6,100 mg/l. Impaired oxygen exchange is believed to be the primary cause of death among sockeye and chinook exposed to volcanic ash. (UW-Fisheries)

Newcombe, C.P., and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

Proposed a ranked response, derived from a stress index, as a means of predicting sublethal and lethal effects on salmonids caused by suspended sediment episodes (1.2 minutes to 361 days) of known intensity (0.7-207,000 mg/l).

Noggle, C.C. 1978. Behavioral, physiological, and lethal effects of suspended sediment on juvenile salmonids. Master's Thesis, University of Washington, Seattle, Washington.

Estimated LC50 values for wild coho presmolts ranged from 1,200 mg/l in August (higher temperatures) to 35,000 mg/l in November in static laboratory bioassays. Gill damage was associated with suspended sediment exposure.

Redding, J.M., C.B. Schreck, and F.H. Everest. 1987. Physiological effects on coho salmon and steelhead of exposure to suspended solids. Transactions of the American Fisheries Society 116:737-744.

Used cortisol levels to detect primary stress responses among yearling coho exposed to suspended topsoil (0.3-0.6 and 2.0-4.0 g/l ranges). Concluded stress associated with exposure to suspended sediments was responsible for lowered resistance to a bacterial pathogen among test groups of yearling steelhead.

** **Servizi, J.A. 1990. Sublethal effects of dredged sediments on juvenile salmon. Pages 57-63 _in_ C.A. Simenstad, editor. Effects of dredging on anadromous Pacific coast fishes workshop proceedings, September 8-9, 1988, Seattle, Washington. Washington Sea Grant Report WSG-WO-90-1, Seattle, Washington.**

Histological, immunological, physiological, and behavioral responses of juvenile salmonids to suspended sediments were reviewed. Chronic exposure to suspended sediments (4 days or longer) may incur a metabolic cost. Juvenile salmon tend to move to the surface in order to avoid plumes of suspended sediment, thus becoming more vulnerable to predation.

Servizi, J.A., and R.W. Gordon. 1990. Acute lethal toxicity of ammonia nd suspended sediment mixtures to chinook salmon (_Oncorhynchus tshawytscha_). Bulletin of Environmental Contamination and Toxicology 44:650-656.

The 96-hr LC50 for juvenile chinook salmon (1.0-7.0 g wet weight) exposed to suspended sediment was 31 g/l at 7.0 °C. The 96-hr toxicities of ammonia-suspended sediment mixtures increased with increasing content of these two constituents. A toxic unit model, separating toxicity results into acute toxicity zones, is provided. (UW-Health Sciences)

Servizi, J.A., and D.W. Martens. 1987. Some effects of suspended Fraser River sediments on sockeye salmon (_Oncorhynchus nerka_). Pages 254-264 _in_ H.D. Smith, L. Margolis, and C.C. Wood, editors. Sockeye salmon (_Oncorhynchus nerka_) population, biology, and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

Suspended sediments caused gill trauma to subyearling (0.78-1.5 g) sockeye salmon at 3,148 mg/l. The 96-hr LC50s of four Fraser River sediments to subyearling sockeye ranged from 1,674 to 17,560 mg/l at 7.8-8.3°C and were related to particle size. Authors conclude tolerance to suspended sediments decreases as angularity and particle size increases. Sockeye smolts suffered slight hypoosmoregulatory impairments when exposed 96 hr to 14,407 mg/l of fine sediment and tended to swim with their backs partly out of the water at 2,678, 7,447, and 14,407 mg/l. Plasma glucose levels increased 39 and 150% in adults exposed to 500 and 1500 mg/l of suspended sediment, respectively. (UW-Fisheries Reserve)

Servizi, J.A., and D.W. Martins. 1991. Effect of temperature, season, and fish size on acute lethality of suspended sediments to coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 48:493-497.

Coho at 0.52 g (4.0 cm) possessed 35% of the tolerance to suspended sediments as larger fish (96-hr LC50s rose sharply as fish length increased from 4.0 to 4.6 cm). The 96-hr LC50s were 8.0 and 8.2 g/l at 7.0°C in May and 22.7 g/l at 7.0°C in December. Tolerance to suspended sediments was temperature dependent, with 96-hr LC50 at 1 and 18°C being 47 and 33%, respectively, of the value at 7°C.

Servizi, J.A., and D.W. Martens. 1992. Sublethal responses of coho salmon (Oncorhynchus kisutch) to suspended sediments. Canadian Journal of Fisheries and Aquatic Sciences 49:1389-1395.

Subyearling (15.2-25.6 g; 11.4-11.2 cm) coho salmon were exposed to sublethal concentrations of Fraser River suspended sediments in the laboratory. Mean avoidance (y) (movement to surface to escape higher suspended sediments at depth) was related to suspended sediments (x) by $y = 0.077 + 4.457(x) - 1.547(X^2) + 0.202(x^3)$. Avoidance was less than 5% up to 2.55 g/l (NTU = 269) of suspended sediment, but rose to 25% at 7 g/l. Estimated threshold for avoidance was 37 NTUs. Blood sugar levels were elevated and directly proportional to suspended sediment exposure.

Sigler, J.W. 1980. Effects of chronic turbidity on feeding, growth and social behavior of steelhead trout and coho salmon. Doctoral dissertation, University of Idaho, Moscow.

Displacement of salmonids occurred as turbidity reached 50 NTU and gill tissue was affected when fish were exposed to 25 NTU for over 5-7 days. (University of Idaho)

** **Sigler, J.W. 1990. Effects of chronic turbidity on anadromous salmonids: Recent studies and assessment techniques perspective. Pages 26-37 in C.A. Simenstad, editor. Effects of dredging on anadromous Pacific coast fishes workshop proceedings, September 8-9, 1988, Seattle, Washington. Washington Sea Grant Report WSG-WO-90-1, Seattle, Washington.**

A review of articles relating to various aspects of the effects of turbidity or suspended sediments on steelhead and coho salmon was completed. Growth of fish exposed to turbidities of 45-80 NTU's for at least 14 days was significantly reduced.

Sigler, J.W., T.C. Bjornn, F.H. Everest. 1984. Effects of chronic turbidity on feeding and growth of steelhead and coho salmon. Transactions of the American Fisheries Society 113:142-150.

Fish were subjected to turbid water conditions and juvenile coho and steelhead emigrated from rearing channels containing 11-49 NTUs. Fish exposed to suspended sediments also grew slower than fish not exposed to suspended sediments.

Smith, D.W. 1978. Tolerance of juvenile chum salmon (<u>Oncorhynchus keta</u>) to suspended sediments. Masters Thesis, University of Washington, Seattle, Washington.

Fifty percent of juvenile chum salmon died when exposed to glacial and marine sediment for 8 to 96 hours at 28-61 g/l.

Smith, O.R. 1939. Placer mining silt and its relation to salmon and trout on the Pacific Coast. Transactions of the American Fisheries Society 69:225-230.

Spawning chinook salmon, when given a choice between silted and unsilted water, selected clear tributaries over muddy waters. Author concluded that silt is harmful to salmon and trout if it is heavy enough to form a layer on the stream bottom or if it persists between floods.

Stober, Q.L., B.D. Ross, C.L. Melby, P.A. Dinnel, T.H. Jagielo, and E.O. Salo. 1981. Effects of suspended volcanic sediment on coho and chinook salmon in the Toutle and Cowlitz Rivers. University of Washington, Fisheries Research Institute, Technical Completion Report FRI-UW-8124.

Acute and sublethal tolerance of pre-smolt, smolt, and adult coho salmon, and chinook salmon smolts to suspended sediments in the Toutle, Cowlitz, and Columbia Rivers and in the laboratory were tested. Results of instream live-box bioassays were 96-hr LC50 values of 1,217 mg/l for coho pre-smolts; 509 mg/l for coho smolts; 488 mg/l for fall chinook smolts. An LC50 for adult salmon could not be determined. Results of static (laboratory) bioassays were 96-hr LC50 values of 18,672 mg/l for pre-smolt coho; 28,184 mg/l for coho smolts in volcanic ash; 2,118 mg/l for coho salmon smolts in "Volclay 200" bentonite; 11,000 mg/l for fall chinook smolts in mudflow sediment; 16,558-19,364 mg/l for fall chinook smolts in volcanic ash. No significant difference in gill condition between fish (pre-smolt and smolt) exposed 96 hours to a sediment-laden river or an unaffected river was observed. (UW-Fisheries)

** Additional sources to date.

Literature review of the effects of suspended sediments on salmonids.

Author	Species & Size	Sediment type/level	LC Values	Other Effects	Lab or Field
Bachman 1984	brown trout	turbid streams	N/A	Ceased feeding at 35 ppm.	Field
Barrett et al. 1992	rainbow trout (87-185 mm)	4-6 NTU 15-30 NTU	N/A	Reactive distances in 15-30 NTU were 45-80% of those observed at 4-6 NTUs. No significant effects on pursuit speed found.	Lab
Berg and Northcote 1985	coho (subyearling)	gravel pit fines 30 NTU (0.02-0.06 mm)	N/A	Elevated cough frequency when exposed 1-48 hours.	Lab
Billard 1982	rainbow trout (eggs)	Kaolinite-rich clay > 1.2 g/L	N/A	Fertilization rates declined when exposed $\geq$ 10 minutes.	Lab
Bisson and Bilby 1982	coho salmon	50-70 NTU	N/A	Displacement occurred at 50 NTU.	Lab
Garric et al. 1990	brown trout	clay 33g/L (< 2 μm) sand (50-200 μm)	LT50 = 20.7 hours LT50 = 10 hours	The strong increase in suspended solids, drop in oxygen, and rise in ammonia concentration seen during dam draining indicated that further study on the oxygen consumption kinetics of the sediment was needed.	Lab
Gregory 1994	chinook salmon (49-55 mm FL) (57-69 mm FL)	 1-810 NTU 1-810 NTU	N/A	Highest foraging rates at 18-150 NTU. Smaller fish preferred foraging in clearer water.	Lab
Lloyd et al. 1987	literature review on salmonids	25-70 NTU	N/A	Ability to find and capture food is impaired.	N/A
Martin et al. 1977	chum salmon (55-93 mm) "healthy"	bottom sediment < 100 μ in diameter	LC10 = 241 mg/L LC50 = 1047 mg/L LC90 = 4611 mg/L		Field
Martin et al. 1977	chum salmon (55-93 mm) "diseased"	bottom sediment < 100 μ in diameter	LC10 = 8-45 mg/L LC50 = 81-415 mg/L LC90 = 769-3810 mg/L	Diseased fish are more susceptible.	Field

Author	Species & Size	Sediment type/level	LC Values	Other Effects	Lab or Field
McCrimmon 1954	Atlantic salmon (parr)	turbid streams < 1150 ppm	N/A	No effects found.	Field
McCrimmon 1954	Atlantic salmon (parr)	sedimented streams unsedimented streams	N/A	2.2% survival 23.4% survival (Young require spaces around gravel for shelter)	Field
Newcomb and Flagg 1983	sockeye salmon (smolts)	Mt. St. Helens volcanic ash (5-100 μm; majority < 15 μm)	36-hr LC50 = 6,100 mg/L		Lab
Newcomb and MacDonald 1991	Oncorhynchus sp.	literature review		Sublethal and lethal effects occur when exposed 1.2 minutes to 361 days to suspended sediments of 0.7-207,000 mg/L.	N/A
Noggle 1978	coho salmon (smolts)	Quillayute Prairie sediment	LC50 = 1,200 mg/L in August LC50 = 35,000 mg/L in November	Gill damage was associated with suspended sediment. In Y-trough tests, coho chose the clear arm at 4,000-12,000 mg/L suspended sediment.	Lab
Redding et al. 1987	coho salmon (yearling) steelhead	suspended topsoil (0.3-4 g/L)	N/A	Stress associated with suspended sediments caused lowered resistance to disease in steelhead salmon.	Lab
Servizi and Gordon 1990	chinook salmon (1-7 g wet weight)	Fraser River Sediments	96-hr LC50 = 31 g/L at 7.0°C.	96-hr toxicities increased as ammonia and sediment content increased. Model to estimate LC50 data for other salmonids in relation to ammonia and sediment is given.	Lab
Servizi and Martens 1987	sockeye salmon (subyearling, 0.78-1.5 g)	Fraser River suspended sediment (< 74 μm)	96-hr LC50 = 1,674-17, 560 mg/L at 7.8-8.3°C	Tolerance to suspended sediments decreases as angularity and particle size increases. Sockeye smolts swam with their backs out of the water when exposed to over 2,678 mg/L of suspended sediment.	Lab

Author	Species & Size	Sediment type/level	LC Values	Other Effects	Lab or Field
Servizi and Martens 1987	sockeye salmon (adult)	Fraser River suspended sediment (< 74 μm)	N/A	No difference in mortality between adults held in 462-553 mg/L suspended sediment and in no sediment for 15 days.	Lab
Servizi and Martens 1991	coho salmon (> 0.52 g, 4.0 cm)	Fraser River suspended sediments	96-hr LC50 = 8-8.2 g/L at 7°C in May 96-hr LC50 = 22.7 g/L at 7°C in December	Tolerance to suspended sediments was temperature-dependent, with lower tolerances at high temperatures (18°C) and low temperatures (1°C).	Lab
Servizi and Martens 1992	coho salmon subyearling (15.2-25.6 g; 11.4 -11.2 cm)	Fraser River suspended sediments	N/A	Avoidance to suspended sediments was < 5% up to 2.55 g/L and 25% at 7 g/L and estimated threshold for avoidance was 37 NTUs. Smaller coho salmon tolerated suspended sediments less than larger individuals. Tolerance was further reduced in fish found to have a viral kidney infection.	Lab
Sigler 1980	steelhead coho salmon		N/A	At 50 NTU, displacement of salmonids occurred. Gill tissue was also affected when fish were exposed to 25 NTUs for over 5-7 days.	N/A
Sigler et al. 1984	steelhead coho salmon		N/A	Fish exposed to 11-49 NTUs emigrated from rearing channels. Fish exposed to suspended sediments also grew slower than those which were not exposed to sediment.	N/A
Smith 1978	chum salmon (juvenile)	glacial and marine sediment	8-96-hr LC50 = 28-61 g/L		Field
Smith 1939	chinook salmon (adult)	placer mining silt	N/A	Spawners chose clear tributaries over "muddy" ones.	Field
Stober et al. 1981	coho salmon (pre-smolt) (smolt) (adult) chinook salmon (smolts)	volcanic ash	 96-hr LC50 = 1,217 mg/L 96-hr LC50 = 509 mg/L undetermined 96-hr LC50 = 488 mg/L	No significant differences in gill condition found between fish exposed 96 hours to a sediment-laden river or an unaffected river.	Field

Author	Species & Size	Sediment type/level	LC Values	Other Effects	Lab or Field
Stober et al. 1981	coho salmon	volcanic ash			Lab
	(pre-smolt)		96-hr LC50 = 18,672 mg/L		
	(smolts)		96-hr LC50 = 28,184 mg/L		
	chinook salmon (smolts)		96-hr LC50 = 16,558-19,364 mg/L		
Stober et al. 1981	coho salmon (smolts)	Volclay 200 bentonite	96-hr LC50 = 2,118 mg/L		Lab
Stober et al. 1981	fall chinook salmon (smolts)	mudflow sediment	96-hr LC50 = 11,000 mg/L		Lab