

A Summary of Tissue Lesions in Aquatic Animals Induced by Controlled Exposures to Environmental Contaminants, Chemotherapeutic Agents, and Potential Carcinogens

THEODORE R. MEYERS and JERRY D. HENDRICKS

Tissue lesions in fish and invertebrates induced by controlled exposures

Theodore R. Meyers, formerly with the Department of Food Science and Technology, Oregon State University, Corvallis, is currently with the School of Fisheries and Science, University of Alaska at Juneau, 11120 Glacier Highway, Juneau, AK 99801. Jerry D. Hendricks is with the Department of Food Science and Technology, Oregon State University, Corvallis, OR 97331. This work was supported in part by cooperative agreement (#CR809344-10) in the NCI/EPA Collaborative Program, Project No. 3, "Effects of Carcinogens, Mutagens and Teratogens in Nonhuman Species (Aquatic Animals)" administered by the Gulf Breeze Environmental Research Laboratory and Public Health Service Grants ES01926, ES00210, and ES00541 from the National Institute of Environmental Health Sciences. This is Technical Paper No. 6383, Oregon Agricultural Experiment Station, Oregon State University. Mention of trade names or commercial products does not imply endorsement.

to various toxic compounds have been described in the literature. However, these reports are few in number, relative to other toxicological data, and widely scattered in several diverse journals. Therefore, retrieval of specific information regarding pathological changes caused by a particular compound(s) is a tedious and difficult task.

This article was written to provide a useful reference for aquatic toxicologists/pathologists by consolidating this descriptive material with key references through 1981. This information is presented in five tables. Table 1 identifies at least 90 environmental contaminants used as pesticides, herbicides, or as industrial chemicals which are categorized in the following manner: Organochlorines, petroleum compounds,

organophosphates, carbamates, heavy metal salts, nitrogenous compounds, miscellaneous compounds, and chemotherapeutic agents. Table 4 lists at least 50 compounds grouped as mycotoxins, plant derivatives, and other chemicals all of which have been tested for carcinogenic activity. Tables 2, 3 and 5 describe and reference histologic and/or ultrastructural lesions or abnormalities caused by these compounds, their routes of exposure, and aquatic species tested.

Comparative discussions of lesions caused by these compounds are not intended here with the exception of the following comment. Most lesions induced by toxicant exposures are often indicative of toxic insult but nonspecific (i.e., hyperplastic, degenerative

Table 1.—Organic and inorganic environmental contaminants and chemotherapeutic agents tested for ability to cause pathological changes in tissues of finfish and shellfish (see Tables 2 and 3)¹.

Organochlorine insecticides	Organochlorine herbicides	Industrial organochlorines	Petroleum compounds	Organophosphate insecticides	Carbamate insecticides	Miscellaneous herbicides	Metals and nitrogenous compounds
Chlordane	Dowpon	Chlorinated wastewater	Crude oil	Abate	Carbaryl (Sevin)	Acrolein	Ammonia (NH ₃)
DDT	Dicamba		Whole	Diazinon	Propoxur	Amitrole-T	Cadmium 109
Dieldrin	Dichlobenil	Polychlorinated biphenyls (PCB's)	Saltwater insoluble	Dimethoate		Atrazine	Cadmium chloride (CdCl ₂)
Endosulfan	Diuron	Aroclor 1248	Saltwater soluble	Dursban		Dinoseb	Copper chloride (CuCl ₂)
Endrin	Dowicide G	Aroclor 1254	Waste motor oil	Dylox		Diquat	Copper nitrate (CuNO ₃)
Heptachlor	Esteron	Miscellaneous PCB's	Oiled sediments	Fenthion		Hydrothol 191	Copper sulphate (CuSO ₄)
Kepone	2,4-D	Carbon tetrachloride (CCl ₄)	Miscellaneous hydrocarbons	Malathion		Paraquat-CL	Landfill leachates
Lindane	Kuron (Silvex)		hydrocarbons and PCB's	Methyl Parathion		Sodium trichloroacetate (NaTA ₂)	Lead acetate trihydrate (C ₄ H ₆ O ₄ Pb)
Methoxychlor	Kurosul		Phenol			Trifluralin	Lead nitrate (PbNO ₃)
Mirex	Tordon 101						Mercuric chloride (HgCl ₂)
Toxaphene	Tordon 22k						Methyl mercury chloride (CH ₃ HgCl ₂)
Chemotherapeutic Agents				Other compounds			Nitrite (NO ₂)
Bradophen (disinfectant)	Neguvon, Masoten			Bis (tri-n-butyltin) oxide (molluscicide)	phosphoramidate (TEPA-insect chemosterilant)		Silver chloride (AgCl)
CuSO ₄ (fungicide, algicide)	Ozone (biocide)			Dimethylsulfoxide (DMSO)	3-trifluoromethyl 4-nitrophenol (TFM-lampricide)		Sodium arsenate (Na ₂ HAsO ₄)
Dipterex	Penicillin G procain sulfate			Sodium lauryl sulfate (SLS-detergent)	Acid-alkaline pH (sulphuric acid; sodium hydroxide)		Sodium arsenite (NaAsO ₂)
Emtrysidina	Oxytetracycline			Triethylene			Zinc chloride (ZnCl ₂)
Formalin (fungicide, ectoparasiticide)	Sulfamethazine						Zinc sulphate (ZnSO ₄)
Hexa-ex (disinfectant)	Sulfonamides						
Kanamycin	Thiabendazole (vermicide)						
Malachite Green (fungicide, ectoparasiticide)	Tobramycin						
Methylene Blue (fungicide, disinfectant)	Yomesan (anthelmintic)						

¹Source: Figure 1 (Meyers and Hendricks, in press) in G. M. Rand and S. Petrocelli (editors), "Principles of aquatic toxicology," Hemisphere Publishing Corporation, N.Y.

Table 2.—Summary of reported gross, histological, and ultrastructural changes in tissues of fish and shellfish resulting from exposures to various chemical compounds. Descriptions and interpretations are provided mostly in the words of the authors cited which may be vague or ambiguous in some cases. For "Exposure routes," W = water, D = diet, IP = intraperitoneal injection, and GI = intragastric intubation. Contaminant abbreviations are defined in Table 1.

Contaminant	Exposure route	Species	Tissues affected	Lesions
Organochlorine insecticides				
Chlordane	W	Lake trout (<i>Salvelinus namaycush</i>)	Liver	Increased amounts of focal hepatocyte vacuolation and degeneration (Eller, unpubl., in Couch, 1975).
DDT	W	Coho salmon (<i>Oncorhynchus kisutch</i>)	Integument Gills Spleen Liver Intestine Brain	Erosion of premaxillary region ¹ (Walsh and Ribelin, 1975). Respiratory epithelial hyperplasia of secondary lamellae ¹ (Walsh and Ribelin, 1975). Hypocellularity and fibroplasia (Walsh and Ribelin, 1975). Hyperemia, petechiae, fatty change, periportal necrosis, disorganized architecture (Walsh and Ribelin, 1975). Hyperemia, lymphocytic infiltration (Walsh and Ribelin, 1975). Hyperemia or hemorrhage (Walsh and Ribelin, 1975).

and/or necrotic) changes making diagnosis of a single causative compound or group of compounds difficult, if not impossible. Only a limited number of toxicants cause lesions in aquatic species which may be useful for diagnostic purposes, although none are pathognomonic; carbaryl causes muscular and neural lesions (Walsh and Ribelin, 1975) while varying degrees of vertebral deformities are caused by kepone (Couch et al., 1977), toxaphene (Mehrle and Mayer, 1975; Mayer et al., 1978), trifluralin (Couch et al., 1979), malathion (Mount and Stephan, 1967; Weis and Weis, 1976), various organophosphates (McCann and Jasper, 1972), carbamates (Carter, 1971), and lead salts (Holcombe et al., 1976; Ozoh 1979a,b). For detailed discussions of these and other less specific lesions the investigator is referred to Meyers and Hendricks (in press) or the appropriate literature sources listed. A discussion of carcinogens and neoplastic lesions in fish is presented by Hendricks (1982).

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Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions		
DDT (cont.)	W	Lake trout	Gills	Respiratory epithelial hyperplasia of secondary lamellae ¹ (Walsh and Ribelin, 1975).		
			Spleen	Paleness, atrophy, hypocellularity, fibroplasia (Walsh and Ribelin, 1975).		
			Liver	Hyperemia, petechiae, fatty change (Walsh and Ribelin, 1975).		
	D	Chinook salmon (<i>O. tshawytscha</i>)	Intestine	Air distension in fry (Burdick et al., 1964), hyperemia and lymphocytic infiltration (Walsh and Ribelin, 1975).		
			Swim bladder	Air distension in fry (Burdick et al., 1964).		
			Brain	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).		
	W	Cutthroat trout (<i>Salmo clarki</i>)	None	(Buhler et al., 1969).		
			None	(Allison et al., 1964).		
	D & W	Rainbow trout (<i>S. gairdneri</i>)	None	(Wood, unpubl., in Walsh and Ribelin, 1975).		
			Liver	Hepatic cell carcinoma (Halver et al., 1962).		
	W	Brown trout (<i>S. trutta</i>)	Liver	Nuclear hypertrophy and cytoplasmic vacuolation of hepatocytes (King, 1962).		
			Kidney	Tubular degeneration and debris in lumina (King, 1962).		
	W	Guppy (<i>Poecilia reticulata</i>)	Intestine	Submucosal vacuolization and degeneration of mucosal epithelium (King, 1962).		
Adrenal cortex (interrenal cells)			Necrosis (King, 1962).			
W	Asian fish sp. (unspecified)	Liver	Severe necrosis (King, 1962).			
		Adrenal cortex (interrenal cells)	Necrosis (King, 1962).			
W	Eel (<i>Anguilla rostrata</i>)	Spleen	Atrophy (King, 1962).			
		Liver	Hepatocyte hypertrophy, degeneration, necrosis (Mathur, 1962).			
W	American oyster † (<i>Crassostrea virginica</i>)	Kidney	Tubular degeneration (Mathur, 1962).			
		Intestine	Submucosal vacuolization, degeneration of mucosal epithelium, loss of goblet cells (Mathur, 1962).			
DDT, Toxaphene and Parathion (mixture)	W	Eel (<i>Anguilla rostrata</i>)	Intestine	ATPase inhibition (Janicki and Kinter, 1971).		
			Pituitary	Degranulation of ϵ cells (DDD) (Ball and Baker, 1969).		
			Digestive diverticula (Smaller nonciliated tubules)	Necrosis of tubular epithelium, reduction in tubule height and dilation of lumina (Lowe et al., 1971b).		
			Gonads	Inhibition of maturation in female oysters with leukocyte infiltration or hyperplasia of germinal epithelium; leukocyte infiltration among spermatozoa in males (Lowe et al., 1971a,b).		
			Vesicular connective tissue	Edema beneath intestinal areas sometimes with infiltration of leukocytes (Lowe et al., 1971b).		
			Mantle, gut, gonads, gills, visceral ganglion & kidney tubules	Secondary infection with a mycelial fungus causing cell lysis, usually without host leukocyte infiltration (Lowe et al., 1971b).		
			W	Various fishes	Liver	Hepatocyte pleomorphism, cytoplasmic vacuoles (Mathur, 1965).
					Gills	Hyperplasia of lamellar respiratory epithelium ¹ and telangiectasia (Walsh and Ribelin, 1975).
			W	Lake trout	Spleen	Paleness, atrophy, hypocellularity ¹ , and fibroplasia (Walsh and Ribelin, 1975).
					Liver	Hyperemia, petechiae or discolored areas, fatty change, congestion of sinusoids and hepatic veins (Walsh and Ribelin, 1975).
W	Coho salmon	Intestine	Hyperemia (Walsh and Ribelin, 1975).			
		Brain	Hyperemia ¹ or hemorrhage (Walsh and Ribelin, 1975).			
W	Coho salmon	Integument	Erosion of premaxillary region ¹ (Walsh and Ribelin, 1975).			
		Gills	Hyperplasia of lamellar respiratory epithelium ¹ and telangiectasia (Walsh and Ribelin, 1975).			
W	Asian fish sp. (<i>Ophiocephalus punctatus</i>) (<i>Trichogaster fasciatus</i>)	Spleen	Hypocellularity ¹ and fibroplasia (Walsh and Ribelin, 1975).			
		Liver	Hyperemia, petechiae, or discolored areas, fatty change, congestion of sinusoids and hepatic veins (Walsh and Ribelin, 1975).			
W	Lake trout	Intestine	Hyperemia (Walsh and Ribelin, 1975).			
		Brain	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).			
W	Coho salmon	Adrenal cortex (interrenal cells)	Hyperplasia (Walsh and Ribelin, 1975).			
		Liver	Hypertrophy of hepatocytes, vacuolar degeneration of cytoplasm and necrosis (Mathur, 1975).			
Endosulfan	W	Lake trout	Liver	Vacuolar degeneration of hepatocytes and localized necrosis (Mathur, 1975).		
			Gills	Telangiectasia and hyperplasia ¹ of lamellar respiratory epithelium (Walsh and Ribelin, 1975).		
W	Coho salmon	Spleen	Paleness, atrophy, hypocellularity, fibroplasia (Walsh and Ribelin, 1975).			
		Liver	Petechiae or discoloration, fatty change (Walsh and Ribelin, 1975).			
W	Coho salmon	Intestine	Hyperemia (Walsh and Ribelin, 1975).			
		Brain	Hyperemia ¹ or hemorrhage (Walsh and Ribelin, 1975).			
W	Coho salmon	Integument	Erosion of premaxillary region ¹ (Walsh and Ribelin, 1975).			
		Spleen	Paleness, atrophy, hypocellularity, and fibroplasia (Walsh and Ribelin, 1975).			
W	Coho salmon	Liver	Petechiae or discolored areas, fatty change (Walsh and Ribelin, 1975).			
		Intestine	Hyperemia (Walsh and Ribelin, 1975).			
Endrin	W	Rainbow trout	Brain	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).		
			Liver	Hepatocyte degeneration (Wood, unpubl., in Couch, 1975).		
D & W	Cutthroat trout	Kidney	Yellow pigment in tubules (Wood, unpubl., in Couch, 1975).			
		Gills	Edema and separation of respiratory epithelium from basement membrane (Eller, 1971).			
W	Spot (<i>Leiostomus xanthurus</i>)	Liver	Suggestive preneoplastic changes which never developed into hepatic cell carcinoma (Eller, 1971).			
		Ovary	Hyperplasia of germinal epithelium and involution of some follicles (Eller, 1971).			
W	Spot (<i>Leiostomus xanthurus</i>)	Pancreas	Islet cell hyperplasia (Eller, 1971).			
		Liver	Focal necrosis of hepatocytes with inflammation and loss of glycogen and lipid (Lowe, 1965).			

†Note: Lesions were absent in oysters exposed to separate concentrations of each compound (Lowe et al., 1971b).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
Endrin (cont.)	W	Spot (cont.)	None	(Johnson, 1968).
	W	Guppy (<i>P. reticulata</i>)	Liver	Fatty change (Mount, 1962).
	W	Fish (sp. not given)	Kidney	Vacuolated cells in glomeruli (Mount and Putnicki, 1966).
Heptachlor	W	Goldfish (<i>Carassius auratus</i>)	Liver	Reduced cytoplasmic vacuolization (Grant and Mehrle, 1970).
	IP	Asian catfish (<i>Channa punctatus</i>)	Thyroid	Reduced follicular cell height (Grant and Mehrle, 1970).
	W	Rainbow trout	Liver	Hypertrophy of hepatocytes and hepatocyte nuclei, centrilobular necrosis, perilobular vacuolization, fibrosis (Sastry and Sharma, 1978).
Kepone	W	Cutthroat trout	Gills	Edema and congestion (Wood, unpubl., in Couch, 1975).
	W	Cutthroat trout	Liver	Heavy bile pigment deposits (Wood, unpubl., in Couch, 1975).
	D & W	Bluegill (<i>Lepomis macrochirus</i>)	None	Edema and congestion (Andrews et al., 1966).
Lindane	W	Rainbow trout	Liver	Hepatocyte degeneration and deposition of bile pigments (Andrews et al., 1966).
	W	Asian fish sp. (<i>O. punctatus</i>)	Peripheral blood	Hepatocyte shrinkage with loss of lipid and glycogen, loss of normal architecture (Andrews et al., 1966).
	W	Asian fish sp. (<i>T. fasciatus</i>)	Vertebral column	Enlarged erythrocytes (Andrews et al., 1966).
Methoxychlor	W	Rainbow trout	Spinal cord	Scoliosis, fractured centra of vertebrae with foci of osteoblastic repair (Couch et al., 1977).
	W	Bluegill	Skeletal muscle	Compression of lateral funiculi by vertebral fractures (Couch et al., 1977).
	W	Carp fry (<i>Cyprinus carpio</i>)	Liver	Distorted myotomal patterns, loss of neurological control of caudal melanocyte pattern (Couch et al., 1977).
Mirex	W	Mummichog (<i>Fundulus heteroclitus</i>)	Liver	Focal necrosis (Wood, unpubl., in Walsh and Ribelin, 1975).
	W	Cutthroat trout	Kidney	Degeneration of tubules (Wood, unpubl., in Walsh and Ribelin, 1975).
	W	Goldfish	Liver	Vacuolar degeneration of hepatocytes with slight to moderate necrosis and atrophy with loss of normal cord pattern (Mathur, 1975).
Toxaphene	W	Bluegill	Liver	Cytoplasmic alterations of hepatocytes, margination of nuclear chromatin and hypertrophy (Mathur, 1975).
	W	Pinfish (<i>Lagodon rhomboides</i>)	Brain	Nonspecific degeneration (Wood, unpubl., in Walsh and Ribelin, 1975; Cope, 1966).
	W	Rainbow trout	Gills	Shrinkage and granulation of hepatocytes, loss of normal cord pattern, eosinophilic globules in capillary lumina (Kennedy et al., 1970).
Organochlorine herbicides	W	Carp	Liver	Vascular congestion (Kennedy et al., 1970).
	W	Coho salmon	Kidney	Increased mucus secretions, respiratory epithelial hyperplasia with "clubbing" and fusion of lamellae, necrosis and desquamation of lamellar respiratory epithelium and vascular congestion or telangiectasia (Lakota et al., 1978).
	W	Bluegill	Intestine	Vascular congestion and hepatocyte degeneration (Lakota et al., 1978).
Dowpon	W	Bluegill	Lateral line canal	None (Lakota et al., 1978).
	W	Cutthroat trout	Gills	None (Lakota et al., 1978).
	W	Goldfish	Gills	Epithelial necrosis (Gardner, 1975).
Dicamba	W	Bluegill	Gills	Fused lamellae (Van Valin et al., 1968).
	W	Bluegill	Gills	Edema and telangiectasia of lamellae (Van Valin et al., 1968).
	W	Bluegill	Gallbladder	Distended with flattened epithelium (Van Valin et al., 1968).
Dichlobenil	W	Bluegill	None	(Van Valin et al., 1968).
	W	Pinfish (<i>Lagodon rhomboides</i>)	None	(Lowe et al., 1971a).
	W	Rainbow trout	Gills	Edema (Wood, unpubl., in Walsh and Ribelin, 1975).
Diuron	W	Fathead minnow (<i>Pimephales promelas</i>)	Liver	Hepatocyte necrosis and disorganization of cord architecture (Wood, unpubl., in Walsh and Ribelin, 1975).
	W	Spot	Spinal vertebrae	Reduced collagen content and hyperfragility (Mehrle and Mayer, 1975).
	W	Channel catfish (<i>Ictalurus punctatus</i>)	Gills	Thickening of lamellar respiratory epithelium (Lowe, 1964).
Dowicide G	W	Spot	Integument	Reduction in mucus cell numbers and increased thickness of epidermis (Mayer et al., 1978).
	W	Channel catfish (<i>Ictalurus punctatus</i>)	Spinal vertebrae	Causes a functional vitamin C deficiency resulting in reduction of vertebral collagen and spinal deformities (Mayer et al., 1978).
	W	Channel catfish (<i>Ictalurus punctatus</i>)	Spinal vertebrae	Causes a functional vitamin C deficiency resulting in reduction of vertebral collagen and spinal deformities (Mayer et al., 1978).
Esteron	W	Carp	Pancreas	Submicroscopic degeneration to acute necrosis of acinar cells (Schulz, 1971).
	W	Coho salmon	None	(Hendricks, 1979).
	W	Bluegill	Gills	Vascular engorgement with lamellar telangiectasia and fusion (Cope, 1966).
2,4-D	W	Bluegill	Liver	Hepatocyte necrosis characterized by pyknosis and karyolysis, fibrosis and adenomatous change (Cope et al., 1969).
	W	Bluegill	Liver	Lamellar telangiectasia, hemorrhage and respiratory epithelial hyperplasia with fusion (McCraren et al., 1969).
	W	Bluegill	Liver	Enlarged sinusoids, hypertrophied, hyperchromic hepatocyte nuclei, less lipid deposition, hepatocyte necrosis in one fish and fatty change in another (Crandall and Goodnight, 1963).
Blood vessels	W	Coho salmon	Gills	Curving of filaments, exfoliation of some chloride cells and congestion of most lamellae resulting in telangiectasia in some (Hendricks, 1979).
	W	Bluegill	Liver	Hepatocyte shrinkage, loss of glycogen, distortion of hepatic cords, atypical hepatocytes (Cope et al., 1970).
	W	Bluegill	Liver	Vascular congestion (Cope et al., 1970).
Lake trout	W	Bluegill	Brain	PAS positive globular masses in lumina (Cope et al., 1970).
	W	Bluegill	Gills	Lamellar respiratory epithelial hyperplasia ¹ , telangiectasia (Walsh and Ribelin, 1975).
	W	Bluegill	Spleen	Hypocellularity ¹ , fibroplasia (Walsh and Ribelin, 1975).
Coho salmon	W	Bluegill	Liver	Hyperemia, fatty change ¹ and congestion of sinusoids and veins (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Pink or red color (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Hyperemic, flaccid (Walsh and Ribelin, 1975).
Coho salmon	W	Bluegill	Liver	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Hyperplasia of lamellae ¹ (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Hypocellularity, fibroplasia (Walsh and Ribelin, 1975).
Coho salmon	W	Bluegill	Liver	Hyperemia, fatty change, congestion of sinusoids and veins (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Hyperemia, fatty change, congestion of sinusoids and veins (Walsh and Ribelin, 1975).
	W	Bluegill	Liver	Hyperemia, fatty change, congestion of sinusoids and veins (Walsh and Ribelin, 1975).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
2,4-D (cont.)	W	Coho salmon (cont.)	Bile Intestine Brain Liver	Pink or red color (Walsh and Ribelin, 1975). Hyperemic, flaccid (Walsh and Ribelin, 1975). Hyperemia or hemorrhage (Walsh and Ribelin, 1975). Hepatocyte shrinkage, loss of glycogen, distortion of cord architecture (Wood, unpubl., in Walsh and Ribelin, 1975).
Kuron (Silvex)	W	Bluegill	Testes	Stimulation of spermatogenesis and exhaustion atrophy (Wood, unpubl., in Walsh and Ribelin, 1975).
Kurosal	W	Bluegill	None	(Wood, unpubl., in Walsh and Ribelin, 1975).
Tordon 101	W	Coho salmon	Liver	Peribiliary necrosis (Hendricks, 1979).
Tordon 22k	W	Coho salmon	Liver Gills	Some hydropic degeneration and some hypertrophy of hepatocytes containing fiber-like strands in the cytoplasm (Hendricks, 1979). Some hypertrophy of respiratory epithelial cells while others had a shrunken appearance (Hendricks, 1979).
Industrial organochlorines				
Chlorinated wastewater	W	Coho salmon	Peripheral blood	Microcytic, hypochromic hemolytic anemia with high percentage of circulating abnormal and immature red blood cells (Buckley et al., 1976); formation of Heinz bodies and Howell-Jolly bodies (Buckley, 1977).
PCB's				
Aroclor 1248	W	Lake trout	Liver	Focal hepatocyte degeneration, cytoplasmic vacuolation and pleomorphism more severe than in control fish (Eller, unpubl., in Couch, 1975).
Aroclor 1254	W	Spot	Liver	Increased fatty change, vacuolation and necrosis of pancreatic acinar tissue around portal tracts with infiltration of lymphocytes, focal hepatocyte necrosis, sinusoidal congestion and presence of ceroid-like inclusion bodies in parenchymal cytoplasm (Couch, 1975).
	D	Rainbow trout	Kidney Liver Spleen	Degeneration of renal tubules characterized by flattening and pyknosis of the epithelium, dilation of the lumina with proteinaceous casts and desquamated epithelial cells (Nestel and Budd, 1975). Variable degree of vacuolation and hepatocyte density of questionable significance (Nestel and Budd, 1975); distinct vacuolation of hepatocytes and enlargement of rough ER no longer adjacent to nuclei or mitochondria (Sivarajah et al., 1978). Less pigment (melanin?) and red pulp per unit area and reduced amounts of white pulp (Nestel and Budd, 1975).
	IP		Testes Ovaries	Ultrastructural damage to spermatozoa particularly in head region — loss of serrations in outer membrane (Sivarajah et al., 1978). Fragmented cytoplasm in oocytes due to enlargement and proliferation of smooth ER (Sivarajah et al., 1978).
	IP	Carp	Liver Testes Ovaries	Enlargement of rough ER (Sivarajah et al., 1978). Ultrastructural damage to spermatozoa particularly in head region — loss of serrations in outer membrane (Sivarajah et al., 1978). Fragmented cytoplasm in oocytes due to enlargement and proliferation of smooth ER (Sivarajah et al., 1978).
	W	American oyster ††	Digestive diverticula Vesicular connective tissue Gonads Intestine	Atrophy of tubular epithelium characterized by cytoplasmic vacuolation, reduction in height and dilation of lumina (Lowe et al., 1972). Loss of compact architecture (edema) with heavy infiltration of leukocytes (Lowe et al., 1972). Leukocyte infiltration (Lowe et al., 1972).
Miscellaneous PCB's	D	Chinook salmon	Intestine Liver	Exfoliation of mucosal epithelium, absence or reduction in brush border and presence of abnormal cytoplasmic inclusion bodies in columnar epithelium (Hawkes et al., 1980). Vesiculated rough endoplasmic reticulum and circular arrays of smooth surfaced membranes and myelin-like bodies in hepatocyte cytoplasm (Hawkes, 1980).
	GI	Channel catfish	Liver	Proliferation of endoplasmic reticulum and "bizarre" whorls of both rough and smooth ER (Hinton et al., 1978; Klaunig et al., 1979).
CCl ₄	IP	Rainbow trout	Liver Peritoneum Intestine Spleen	Vacuolation of hepatocytes and compression of sinusoids with eventual hepatocyte necrosis (Racicot et al., 1975); mottled with blanched areas, eosinophilic degeneration and hydropic degeneration of hepatocytes, pyknosis and coagulative necrosis in subcapsular areas while liquefactive necrosis and karyolysis predominated in centrilobular regions (Gingerich et al., 1978). Dark red serous ascites and hemorrhagic inflammation (Gingerich et al., 1978). Hemorrhagic inflammation and multiple thrombi in ventral intestinal vein (Gingerich et al., 1978). Mottled with blanched areas (Gingerich et al., 1978).
Petroleum compounds				
Crude oil	W	Atlantic silverside (<i>Menidia menidia</i>)	Olfactory organs Heart Pseudobranch Anterior brain	Hyperplasia of sustentacular epithelium, cellular degeneration and necrosis of olfactory mucosa (Gardner, 1975). Degeneration of ventricular myocardium (Gardner, 1975). Degeneration of secretory cells (Gardner, 1975).
Whole	W	Pacific herring (embryos) (<i>Clupea pallasii</i>)	Skeletal muscle	Enlarged and irregularly shaped nonmembrane bound perinuclear and intracellular spaces (Cameron and Smith, 1980).
	D	Rainbow trout	Liver Eye lens	Numerous swollen mitochondria with some disruption of internal membranes and cristae; intercellular breakdown of membranes (Cameron and Smith, 1980). Loss of glycogen reserves in hepatocytes, proliferation of endoplasmic reticulum and presence of cochlear ribosomes, fibrosis around sinusoids (Hawkes, 1977). Enlarged, abnormally soft, probably resulting from shriveling and degeneration of lens fibers observed by TEM (Hawkes, 1977).
Saltwater insoluble	W	Atlantic silverside	Olfactory organs	Hyperplasia of sustentacular epithelium and necrosis, vasodilation of submucosa (Gardner, 1975).
Saltwater soluble	W	Atlantic silverside	Olfactory organs	Epithelial metaplasia of olfactory mucosa with appearance of extracellular refractile rods; some hyperplasia and cytoplasmic degeneration in neurosensory and sustentacular epithelium in basal region of olfactory lamellae (Gardner, 1975).

††Note: Lesions reversible following 12 weeks depuration in PCB-free seawater (Lowe et al., 1972).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
Crude oil (cont.) Saltwater soluble (cont.)	W	Coho salmon; starry flounder (<i>Platichthys stellatus</i>)	Gills	Sloughing of first 2-3 layers of surface respiratory epithelial cells with excessive mucus exudation (Hawkes, 1977).
	W	English sole (<i>Parophrys vetulus</i>)	Integument	Increased numbers of mucus glands which appeared dilated when observed with SEM (Hawkes, 1977).
	W	Sand sole (<i>Psetichthys melanostictus</i>)	Nares epithelium	Severe damage to receptor organelles including degeneration of chemosensory cilia and loss of microridges circumscribing epithelial cells surrounding olfactory organs (Hawkes, 1980).
Waste motor oil Oiled sediments Oil slick	W	Atlantic silverside	Blood vessels	Vascular anomalies (Gardner, 1978).
	W	English sole	Liver	Increase in lipid volume per hepatocyte (McCain et al., 1978).
	W	Cunner (<i>Tautoglabrus adspersus</i>)	Eye lens	Degeneration of lens fibers (Payne et al., 1978).
Miscellaneous hydrocarbons	D	Chinook salmon	Intestine	Abnormal inclusion bodies in apical cytoplasm of mucosal columnar epithelium, cytoplasmic vesiculation in columnar cells near luminal surface and abnormal electron lucent cytoplasm and increased amounts of granular endoplasmic reticulum in basal mucosal cells (Hawkes et al., 1980).
Miscellaneous hydrocarbons and PCB's	D	Chinook salmon	Intestine	Increased exfoliation of mucosa, reduced brush border, diffuse distribution of mitochondria in cytoplasm, changes in vesiculation of cytoplasm near brush border, cytoplasmic inclusion bodies throughout cell, increased endoplasmic reticulum and reduction in cytoplasmic density (Hawkes et al., 1980).
Naphthalene	W	Mummichog	Gills	Hemorrhage at base of filaments and respiratory epithelial hyperplasia (DiMichele and Taylor, 1978).
			Neurosensory organs	Degeneration and necrosis of sensory epithelium and sustentacular cells (DiMichele and Taylor, 1978).
			Pancreas; liver; kidney; brain	Vascular congestion and infarction (DiMichele and Taylor, 1978).
			Adrenal cortex (interrenal cells)	Hypertrophy and necrosis (DiMichele and Taylor, 1978).
			Intestine	Necrosis and sloughing of mucosa (DiMichele and Taylor, 1978).
Phenol	W	Bream (<i>Abramis brama</i>)	Skeletal muscle	Necrosis (DiMichele and Taylor, 1978).
			Gills	Respiratory epithelial necrosis, extravasation of blood in lamellae (Waluga, 1966b).
			Integument	Increased numbers of mucus glands which were distended (Waluga, 1966a).
			Kidney	Gross discoloration with congestion of vessels (Waluga, 1966a).
			Gills	Discharged mucus glands and generalized inflammation (Reichenbach-Klinke, 1965).
	W	14 assorted fishes	Integument	Swollen epidermis and generalized inflammation (Reichenbach-Klinke, 1965).
			Gills; pharynx	Necrosis and erosion of epithelium with generalized inflammation of gills (Mitrovic et al., 1968).
			Gills	Respiratory epithelial necrosis and desquamation, distension of hemolymph sinuses containing an amorphous precipitate (Fries and Tripp, 1976).
			Intestine	Epithelial necrosis and sloughing (Fries and Tripp, 1976).
			Digestive diverticula	Tubular epithelial necrosis and sloughing (Fries and Tripp, 1976).
Organophosphate insecticides	W	Bluegill	Liver	Atrophy distortion of muralia, variability in stain affinity of hepatocytes, large foci of edema, congestion and hepatocyte necrosis (Eller, unpubl. in Couch, 1975).
			Pancreas	Acinar cell necrosis (Eller, unpubl. in Couch, 1975).
Diazinon	W	Asian catfish	Intestine	Cytoplasmic vacuolation and loss of structural integrity of mucosal folds, granular inclusions in mucosal and submucosal regions, dilation of submucosal vasculature, necrosis of submucosa, and degeneration of intestinal smooth muscle layers (Anees, 1976).
			Liver; kidney	Granular dystrophy and cytoplasmic vacuolation (Anees, 1976).
Dimethoate	W	Asian catfish	Intestine	Moderate cytoplasmic vacuolation of villi extremities, vascular dilation and necrosis in submucosa and slight degeneration of smooth muscle layers (Anees, 1976).
Dursban	W	Sheepshead minnow	Liver; kidney	Granular dystrophy and cytoplasmic vacuolation (Anees, 1976).
Dylox	W	Rainbow trout	Liver	Congestion, fatty change secondary to change in food consumption (Lowe, pers. commun., in Couch, 1975).
			Gills	Vacuolation in cytoplasm of hepatocytes (Matton and LaHam, 1969).
Fenthion	W	Cichlids (<i>Herotilapia multispinosa</i>) (<i>Tilapia leucosticta</i>)	Gills	Hyperplasia and separation of lamellar respiratory epithelium from basement membranes, telangiectasia, and thrombosis (Jauch, 1979).
			Gills	Severe respiratory epithelial hyperplasia and lamellar fusion (Jauch, 1979).
Malathion	W	Rainbow trout	Gills	Edema and respiratory epithelial separation (Wood, unpubl. in Walsh and Ribelin, 1975).
			Liver	Nonspecific degeneration (Wood, unpubl. in Walsh and Ribelin, 1975).
			None	(Allison et al., 1964).
			Cutthroat trout	Hemorrhage at base of dorsal fin (Walsh and Ribelin, 1975).
			Lake trout	Hyperplasia of lamellar respiratory epithelium ¹ (Walsh and Ribelin, 1975).
	W	Coho salmon	Gills	Hypocellularity ¹ and fibroplasia (Walsh and Ribelin, 1975).
			Liver	Fatty change ¹ (Walsh and Ribelin, 1975).
			Intestine	Hyperemia (Walsh and Ribelin, 1975).
			Brain	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).
			Integument	Erosion of premaxillary region ¹ (Walsh and Ribelin, 1975).
Methyl Parathion	W	Rainbow trout	Gills	Hypertrophy and hyperplasia ¹ of lamellar respiratory epithelium, telangiectasia (Walsh and Ribelin, 1975).
			Spleen	Hypocellularity ¹ and fibroplasia (Walsh and Ribelin, 1975).
			Liver	Fatty change ¹ and glycogen deposits (Walsh and Ribelin, 1975).
			Gall bladder	Alteration of epithelium (Walsh and Ribelin, 1975).
			Intestine	Hyperemia (Walsh and Ribelin, 1975).
	W	Rainbow trout	Brain	Hyperemia or hemorrhage (Walsh and Ribelin, 1975).
			Gills	Marked respiratory epithelial hyperplasia (Wood, unpubl. in Walsh and Ribelin, 1975).
	W		Liver	Swelling of hepatocytes and sinusoid congestion (Wood, unpubl. in Walsh and Ribelin, 1975).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions	
Methyl Parathion (cont.)	W	Rainbow trout (cont.)	Kidney	Proteinaceous casts in Bowman's space and lumina of collecting tubules (Wood, unpubl. in Walsh and Ribelin, 1975).	
	W	Asian catfish	Intestine Liver; kidney	Necrotic mucosa, dilated submucosal vasculature, and irregular pattern of cellular structures (Anees, 1976). Granular dystrophy and cytoplasmic vacuolation (Anees, 1976).	
Carbamate insecticides Carbaryl (Sevin)	W	Rainbow trout	Visceral fat	Unspecified (Lowe, 1967).	
	W	Spot	Liver	Cytoplasmic vacuolation (Couch, 1975).	
	W	Lake trout	Gills	Hyperplasia of lamellar respiratory epithelium ¹ and telangiectasia of lamellae (Walsh and Ribelin, 1975).	
			Eye	Hemorrhage in anterior chamber (Walsh and Ribelin, 1975).	
			Skeletal muscle	Hemorrhage near vertebrae and atrophy near lateral line (Walsh and Ribelin, 1975).	
			Fat Spleen Liver Brain	Myxomatous degeneration (Walsh and Ribelin, 1975). Hypocellularity and fibroplasia (Walsh and Ribelin, 1975). Fatty change (Walsh and Ribelin, 1975). Vacuolation of the lateral geniculate body (Walsh and Ribelin, 1975).	
	W	Coho salmon	Integument Skeletal muscle	Erosion of premaxillary region ¹ (Walsh and Ribelin, 1975). Hemorrhage near vertebrae and atrophy near lateral line (Walsh and Ribelin, 1975).	
			Fat Spleen Liver Brain	Myxomatous degeneration (Walsh and Ribelin, 1975). Hypocellularity and fibroplasia (Walsh and Ribelin, 1975). Fatty change (Walsh and Ribelin, 1975). Vacuolation of molecular layer of optic tectum (Walsh and Ribelin, 1975).	
	W	Bent-nosed clam (<i>Macoma nasuta</i>)	Gills; mantle; siphon; suprabranchial gland	Epithelial vacuolation, pyknosis and necrosis with ultimate sloughing in the first 3 tissues (Armstrong and Millemann, 1974).	
Propoxur	W	Carp fry	Gills	Increased mucus secretion, respiratory epithelial hyperplasia with "clubbing" and fusion of lamellae, vascular congestion, telangiectasia and desquamation (Lakota et al., 1978).	
			Liver	Hepatocyte degeneration (Lakota et al., 1978).	
Miscellaneous herbicides Acolein	W	Coho salmon	Gills	Respiratory epithelium totally destroyed, necrotic, and sloughed (Hendricks, 1979).	
			Esophagus Liver Kidney	Massive necrosis of all 4 tunics (Hendricks, 1979). Separation of hepatocytes within muralia and some necrosis (Hendricks, 1979). Congestion with considerable debris and precipitate in tubule lumina, severe necrosis of both segments of proximal tubule in one case (Hendricks, 1979).	
			Liver	Lamellar respiratory epithelium with hydropic degeneration showing separation from underlying pillar cells (Hendricks, 1979).	
Amitrole-T	W	Coho salmon	Gills	Hepatocytes showing either hydropic degeneration or diffuse coagulative necrosis in approximately 25 percent of parenchymal cells (Hendricks, 1979).	
			Kidney	Coagulative necrosis of all regions of the nephrons and most of the hematopoietic tissue (Hendricks, 1979).	
Atrazine	W	Lake trout	Integument Gills	Hypersecretion of mucus (Walsh and Ribelin, 1975). Hypersecretion of mucus, hyperplasia of lamellar respiratory epithelium ¹ , and telangiectasia ¹ (Walsh and Ribelin, 1975).	
			Skeletal muscle Spleen	Edema of myotomes (Walsh and Ribelin, 1975). Pale ness, atrophy, hypocellularity with fibroplasia (Walsh and Ribelin, 1975).	
			Abdomen; stomach Stomach	Distension with thick mucus (Walsh and Ribelin, 1975). Edema ¹ (Walsh and Ribelin, 1975).	
			Intestine Pyloric caecae; ureters; urinary and swim bladders	Hyperemia and edema ¹ (Walsh and Ribelin, 1975). Edema (Walsh and Ribelin, 1975).	
		W	Coho salmon	Integument	Erosion of premaxillary region and hypersecretion of mucus (Walsh and Ribelin, 1975).
				Gills	Hypersecretion of mucus, hyperplasia of lamellar respiratory epithelium ¹ and telangiectasia ¹ (Walsh and Ribelin, 1975); hypertrophy of gill respiratory epithelium and large aneurysms at the base of filaments (Hendricks, 1979).
			Eye Skeletal muscle Spleen	Exophthalmos (Walsh and Ribelin, 1975). Edema of myotomes (Walsh and Ribelin, 1975). Hypocellularity ¹ and fibroplasia ¹ (Walsh and Ribelin, 1975).	
			Stomach; abdomen Stomach Pyloric caecae; swim and urinary bladders; ureters Intestine	Distension with thick mucus (Walsh and Ribelin, 1975). Edema ¹ (Walsh and Ribelin, 1975). Edema (Walsh and Ribelin, 1975). Hyperemia and edema ¹ (Walsh and Ribelin, 1975).	
Dinoseb	W	Coho salmon	Gills Liver Kidney	Total necrosis and sloughing of lamellar respiratory epithelium (Hendricks, 1979). Diffuse necrosis of parenchymal cells (Hendricks, 1979). Necrosis of all regions of tubules and most of hematopoietic tissue (Hendricks, 1979).	
Diquat	W	Coho salmon	Gills	Hypertrophy and hyperplasia of lamellar and interlamellar epithelium (Hendricks, 1979).	
			Liver	Several foci of degenerate and occasionally necrotic parenchymal cells (Hendricks, 1979).	
Hydrothol 191	W	Redear sunfish (<i>Lepomis microlophus</i>)	Kidney Gills	Numerous degenerate and some necrotic tubule cells (Hendricks, 1979). Reversible respiratory epithelial hyperplasia with lamellar and filament fusions (Eller, 1969).	
			Liver	Inflammation, pigmented swollen hepatocytes progressing to bizarre cells and distorted cords (Eller, 1969).	
			Testes Blood vessels	Development of ova-like cells in follicles (Eller, 1969). Spherical purple-red deposits within lumina (Eller, 1969).	

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions	
Paraquat-CL	W	Coho salmon	Gills	Almost complete sloughing of respiratory epithelium while remaining epithelial cells were degenerate or necrotic (Hendricks, 1979).	
			Liver	Low grade hydropic degeneration particularly in centrilobular areas (Hendricks, 1979).	
NaTA ₂	W	Carp	Kidney Gills	Necrosis of cells in first and second proximal tubules (Hendricks, 1979). Hyperplasia of mucus cells with eventual necrosis of lamellar epithelium (Schultz, 1970).	
Trifluralin	W	Sheepshead minnow	Skeletal muscle Vertebral column	Degenerative atrophy of myotomes (Schulz, 1970). Vertebral dysplasia characterized by near-symmetrical hypertrophy of vertebrae with foci of osteoblasts and fibroblasts actively producing bone and bone precursors, hypertrophy of notochord, compression of spinal cord from vertebral outgrowth and fusion of vertebrae (Couch et al., 1979).	
			Kidney	Compression of mesonephric ducts from outgrowth of vertebrae (Couch et al., 1979).	
Other compounds Bis(tri-n-butyltin) oxide	W	Rainbow trout	Gills	Respiratory epithelial degeneration with separation from basement membrane, vacuolation and vasodilation; chloride cell degeneration with hypertrophied perinuclear space and smooth endoplasmic reticulum, mitochondria having disorganized cristae and ruptured membranes (Chliamovitch and Kuhn, 1977).	
			Liver	Sinusoid congestion, thinning and separation of biliary epithelium from basement membrane accompanied by some necrosis (Chliamovitch and Kuhn, 1977).	
			Integument	Excessive mucus secretion (Chliamovitch and Kuhn, 1977).	
			Eye	Corneal degeneration with necrosis of external squamous epithelium and vacuolation of basal epithelium; hemorrhage and leucocyte infiltration of limbus corneae (Chliamovitch and Kuhn, 1977).	
DMSO	IP	Rainbow trout, chinook salmon, coho salmon, sockeye salmon (<i>Oncorhynchus nerka</i>)	Gills	Swelling, fusion and edema of lamellae with moderate respiratory epithelial hypertrophy, some necrosis and desquamation; hypertrophy of albuminous gland cells (Benville et al., 1968).	
			Kidney	Glomerular edema with cellular debris in Bowman's space; hypoplasia, pyknosis and karyorrhexis of hematopoietic cells (Benville et al., 1968).	
			Liver	Subcapsular and portal necrosis (Benville et al., 1968).	
			Pancreas	Subcapsular necrosis (Benville et al., 1968).	
			Spleen	Subcapsular necrosis, pyknosis and karyorrhexis of blood cells (Benville et al., 1968).	
SLS	W	Rainbow trout	Brain; meninges	Engorgement and dilation of vessels; cerebral edema (Benville et al., 1968).	
			Gills	Hypertrophy, necrosis, and desquamation of filamental and lamellar epithelium with enlarged intercellular lymphoid spaces infiltrated by lymphocytes and granulocytes; chloride cells with pyknotic nuclei; occluded vascular spaces and hematomas present (Abel and Skidmore, 1975).	
TEPA TFM	W	Goldfish	Adrenal cortex (interrenal cells)	Increase in nuclear diameter and number and size of nucleoli with more extensive and intensively staining cytoplasm; atrophy of cells with clumping of nucleoplasm (Bromage and Fuchs, 1976).	
		Guppy	Testes	Atrophy and hypospermia (Stock and Cope, 1969).	
TFM	W	Rainbow trout	Gills	Erythema of pharyngeal area, heavy mucus secretion and lamellar edema (Christie and Battle, 1963).	
		Lamprey (<i>Petromyzon marinus</i>)	Gills	Erythema and swelling of pharyngeal area, heavy mucus secretion and lamellar edema (Christie and Battle, 1963).	
		Liver	Erythema (Christie and Battle, 1963).		
		Skeletal muscle Cloaca	Myotomal edema (Christie and Battle, 1963). Erythema and increased mucus secretion (Christie and Battle, 1963).		
Acid-alkaline water H ₂ SO ₄ -NaOH	W	Brook trout (<i>Salvelinus fontinalis</i>) Ranges of pH >9.0 <5.6	Gills	Separation of endothelial and epithelial cells from pillar cells (Daye and Garside, 1976).	
			>9.0 <4.8	Cornea	Desquamation of corneal epithelium often preceded by loss of distinct stratification of epithelial cells and/or poor differentiation between epithelium and substantia propria; considerable swelling of substantia propria following sloughing of epithelial layer during acute alkaline conditions (Daye and Garside, 1976).
			≥9.5 - 2.2	Eye lens	Degenerative changes consisting of disorganized structure of capsule, lens epithelium, and fibers such that boundaries become indistinct; enlargement of capsule at extreme acid pH (Daye and Garside, 1976).
			>9.5 <4.8	Olfactory organs	Hypertrophy and increase in numbers of goblet cells in olfactory epithelium; cellular vacuolation progressing to "condensation of nuclear bodies" (pyknosis) in cells of lamina propria (Daye and Garside, 1976).
			>9.0 ≤4.2	Integument	Hypertrophy and hypersecretion of mucus goblet cells; degeneration, condensation of nuclear bodies and desquamation of stratified epithelial cells of epidermis followed by degenerative changes in exposed dermis (Daye and Garside, 1976).
			>10 <2.0	Esophagus	Vacuolation and nuclear condensation of mucosal epithelial cells (Daye and Garside, 1976).
			Metals and nitrogenous compounds Ammonia	W	Rainbow trout
Liver	Cytoplasmic degeneration of hepatocytes around central veins, fatty change, dilation of sinusoids, and focal necrosis of hepatic parenchyma (Smith and Piper, 1975).				
Intestine Spleen	Mild necrosis and desquamation of mucosa (Smith and Piper, 1975). Reduction of lymphoid elements (Smith and Piper, 1975).				
W	Rainbow trout fry	Gills		Hypertrophy of lamellar respiratory epithelium with some karyolysis and karyorrhexis occurring at higher dosages (Burkhalter and Kaya, 1977).	

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
Ammonia (cont.)	W	Rainbow trout fry (cont.)	Yolk sac	Developmental retardation with failure to absorb the yolk sac and occurrence of blue sac disease syndrome (Burkhalter and Kaya, 1977).
Cadmium 109	W	Medaka fry (<i>Oryzias latipes</i>)	Brain	Nuclear pyknosis (Aoki, 1978).
CdCl ₂	W	Mummichog	Gills	Focal hypertrophy of filaments and hyperplasia of lamellar and filament epithelium accompanied by high mitotic index, necrosis and desquamation of epithelium and lymphocyte infiltration (Gardner and Yevich, 1970).
			Intestine	Distension of anterior portion, epithelial hypertrophy, increased secretion of mucous with mucoid casts from anus; necrosis of mucosa with desquamation of epithelial cells; edema, focal necrosis and lymphocytic infiltration of submucosa (Gardner and Yevich, 1970).
			Peripheral blood	Numbers of eosinophilic granulocytes increased, some having deformed nuclei, cytoplasmic vacuolation, and reduction in granular mass; nuclei of thrombocytes became irregularly shaped (Gardner and Yevich, 1970); poikilocytosis and anisocytosis primarily in erythrocytes (Gardner, 1975).
			Thyroid gland	Possible hyperplasia of follicles? (Gardner, 1975).
			Kidney	Reduction of pronephric numbers of mature eosinophilic granulocytes (Gardner and Yevich, 1970).
	W	Brook trout	Testes	Purple-brown mottling throughout, necrosis of tubular boundary cells, hemorrhage, vasodilation, and congestion (Sangalang and O'Halloran, 1972).
	W	Cunner	Gills	Equivocal lesions, possibly artefactual (Newman and MacLean, 1974).
			Integument	Swelling of epithelial cells and reduced mucus secretion (Newman and MacLean, 1974).
			Peripheral blood	Poikilocytosis, karyorrhexis and abundant "smudge" cells among erythrocytes; lymphocytopenia, thrombocytopenia and neutrophilia (Newman and MacLean, 1974).
			Intestine	Swollen mucosal epithelium with hypertrophied nuclei and prominent nucleoli; necrosis and desquamation of mucosal epithelium with cellular debris and mucus in lumen (Newman and MacLean, 1974).
			Kidney	Diffuse tubular necrosis with sloughed epithelial cells and hyalin casts in dilated tubule lumina; erythrophagocytosis and reduction or absence of hemosiderin (Newman and MacLean, 1974).
	IP	Goldfish	Testes	Lower mean index of spermatogenic development; increased numbers of macrophages with phagocytized debris forming granulomas in some cases; necrosis of primary germ cells with atrophy of seminiferous tubules resulting in fibrosis and infiltration of mononuclear inflammatory cells (Tafaneli and Summerfelt, 1975).
			Ovaries	Decreased frequency of oocyte maturation (Tafaneli and Summerfelt, 1975).
			Kidney	Abundant interstitial macrophage accumulation usually forming granulomas, some tubular atrophy (Tafaneli and Summerfelt, 1975).
			Liver	Formation of macrophage granulomas (Tafaneli and Summerfelt, 1975).
	W	Sapo (<i>Halobatrachus didactylus</i>)	Peripheral blood	Erythrocyte anisocytosis, poikilocytosis, anisochromasia, microcytosis, karyorrhexis, cytoplasmic vacuolation and hyperchromasia, presence of fusiform shaped cells, and morphological alterations of red blood cell nuclei (Gutierrez et al., 1978).
			Intestine	Loss of normal nuclear orientation in mucosal epithelium, nuclear hyperchromasia, cytoplasmic vacuolation and epithelial necrosis with debris in lumen (Gutierrez et al., 1978).
			Liver	Increase in connective tissue and numbers of hepatocyte nuclei (Gutierrez et al., 1978).
			Kidney	Renal tubular degeneration, nuclei not in normal position and hyperchromatic, and dilated lumina filled with amorphous eosinophilic material (Gutierrez et al., 1978).
	W	Spot	Kidney	Focal degeneration of first and second proximal tubules with granular, basophilic, and vacuolated cytoplasm containing swollen or dense contracted mitochondria, some with a granular matrix and focal electron densities; third proximal tubules with increased numbers of vacuoles, lipid droplets, autophagic vacuoles, nuclei with marginated chromatin, swollen nuclear envelopes and basal membranes contorted into myelin-like figures and cellular casts in the lumina; Bowman's space slightly swollen with cell debris (Hawkins et al., 1980).
	W	Langostino (shrimp) (<i>Penaeus kerathurus</i>)	Hepatopancreas	Digestive diverticular epithelium reduced in height, tubules dilated with enlarged circular lumina (Establier et al., 1978c).
CdCl ₂ ; CdCl ₂ & CuCl ₂ ; CdCl ₂ & ZnCl ₂	W	Mummichog	Kidney	Degenerative changes and necrosis in epithelial cells of proximal tubules containing granular casts and nuclear debris (Gardner and Yevich, 1970; Eisler and Gardner, 1973); necrotic tubule epithelium appearing as pink staining granular material with either pyknotic nuclei or nuclear debris (Eisler and Gardner, 1973).
CuCl ₂	W & IP	Mummichog	Liver	Focal necrosis (Gardner and LaRoche, 1973).
			Kidney	Unspecified renal damage (Gardner and LaRoche, 1973).
			Lateral line canal (cephalic extension)	Necrosis of sensory and sustentacular epithelium characterized by nuclear pyknosis, karyorrhexis, swelling and reduction of staining capacity of cell cytoplasm; reduction in numbers of goblet cells lining canal and no effect on basal cuboidal cells (Gardner and LaRoche, 1973).
			Olfactory organs	Necrosis of epithelial receptor cells, hyperplasia of sustentacular epithelium with cyst-like formations containing cellular debris and remnants of sensory tissue (Gardner and LaRoche, 1973).
	W	Atlantic silverside	Lateral line canal (cephalic extension)	Changes similar to those above in the mummichog (Gardner and LaRoche, 1973).
			Olfactory organ	Complete necrosis of all cellular elements accompanied by vasodilation and congestion of vessels in submucosa (Gardner and LaRoche, 1973).
			Brain	Vasodilation and congestion with rupture and hemorrhage of the meninx primitiva (Gardner and LaRoche, 1973).
			Eye	Hemorrhaging of periorbital connective tissue (Gardner and LaRoche, 1973).
			Kidney	Cytoplasmic vacuolation and discontinuity of cell walls in basal region of epithelium lining proximal and collecting tubules; clumping of nuclear chromatin in same cells (Eisler and Gardner, 1973).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
CuCl ₂ ; CuCl ₂ & ZnCl ₂ ; CuCl ₂ & ZnCl ₂ & CdCl ₂ ; CuCl ₂ & CdCl ₂ (cont.)	W	Mummichog (cont.)	Lateral line (cephalic extension)	Pyknotic nuclei and clear cytoplasm in swollen epithelial cells beneath canal lining; occasional neuromast nuclei with enlarged nucleoli and loss of nuclei in others (Eisler and Gardner, 1973).
			Oral cavity	Focal pyknosis and hyperchromasia of squamous cell nuclei progressing to complete necrosis (Eisler and Gardner, 1973).
CuCl ₂ & ZnCl ₂ & CdCl ₂	W	Mummichog	Gills	Significant deposits of mucus within interlamellar spaces due to hypersecretion by goblet cells (Eisler and Gardner, 1973).
CuNO ₃	W	Zebra fish (fry) (<i>Brachydanio rerio</i>)	Central nervous system	Spirality (Ozoh, 1979a).
CuSO ₄	W	Winter flounder (<i>Pseudopleuronectes americanus</i>)	Gills	Progressive degeneration of lamellar respiratory epithelium with vacuolation and reduction in height of epithelial layer, overabundance of enlarged chloride cells, fewer but swollen goblet cells, lamellar fusion with eventual desquamation and necrosis of epithelial layer. Ultrastructural changes in epithelium included formation of autophagosomes, vacuoles, myelin-like bodies and apical vesicles in the cytoplasm, reduction in thickness of apical homogeneous cytoplasm of epithelial cells, increased amounts of particulate material on epithelial cell surfaces (Baker, 1969).
			Liver Kidney	Centrilobular fatty change in hepatocytes (Baker, 1969). Necrosis of hematopoietic tissue, size reduction and vacuolation of renal tubular epithelium with disintegration of apical cytoplasm, and presence of dense material in tubule lumina (Baker, 1969).
Landfill leachates	W	Asian fish sp. (<i>Heteropneustes fossilis</i>)	Gills	Disorganized appearance of lamellae, vacuolation of respiratory epithelial cells, and reduction in goblet cell number (Bhatnagar and Shrivastava, 1975).
			Stomach Kidney	Degeneration of gastric epithelium (Bhatnagar and Shrivastava, 1975). Necrosis of hematopoietic tissue, unspecified degeneration of cellular structure, and contraction of cytoplasm (Bhatnagar and Shrivastava, 1975).
C ₄ H ₆ O ₄ Pb	IP	Zebra cichlid (Fry) (<i>Cichlasoma nigrofasciatum</i>)	Adrenal cortex (inter-renal cells)	Hypertrophy of nuclei and nucleoli, vacuolation of cytoplasm, abundant mitotic figures and prominent sinusoids concomitant with increased plasma cortisol levels (McBride et al., 1979).
			Fins; tail Eyes Heart Vertebral column Melanocytes	Erosion of epithelium and atrophy (Ozoh, 1979b). Anophthalmia and microphthalmia (Ozoh, 1979b). Hypotonicity with poor circulation and hemostasis (Ozoh, 1979b). Lordoscoliosis (Ozoh, 1979b).
PbNO ₃	W	Asian catfish	Intestine; pyloric caecae	Abnormal melanogenesis of melanophores (Ozoh, 1979b).
			Liver	Reduction in height of villi, desquamation of degenerate and necrotic mucosal epithelium from the tips and crypts of villi with underlying infiltration of inflammatory cells in the lamina propria (Sastry and Gupta, 1978b).
HgCl ₂	W	Zebra fish (embryos & fry)	Integument Yolk sac Other	Disorganization of muralia, focal hepatocyte necrosis especially in centrilobular areas with portal and periobular infiltration of inflammatory cells, slight perivascular fibrosis, dilation of interhepatocyte spaces, and diffuse deposition of lipofuscin granules within hepatocyte cytoplasm (Sastry and Gupta, 1978b). Epitheliomas, tail erosion (Ozoh, 1979a). Poor resorption (Ozoh, 1979a).
			Gills	Suppression of CuNO ₃ induced abnormalities (Ozoh, 1979a).
W & IP	W	Rainbow trout (fry, fingerlings)	Kidney	Some degree of respiratory epithelial hyperplasia but no significant increase in mitotic activity; extensive in situ necrosis with karyorrhexis of respiratory epithelial nuclei (Wobeser, 1975a).
			Hogchoker (<i>Trinectes maculatus</i>)	Selective necrosis of second proximal tubules; earlier ultrastructural changes include distortion of microvilli, dilation of endoplasmic reticulum and nuclear envelopes, swelling of mitochondria with flocculent densities (Trump et al., 1975).
W	W	Mummichog	Neurosensory organs	Necrosis of all cellular elements of lateral line canals, severe degenerative changes in olfactory organs (Gardner, 1975).
			Kidney	Epithelium of proximal tubules with cytoplasmic vacuolation, dilation of nuclear envelopes, mitochondrial swelling, and distortion of microvilli (Wassermann and Koeppe, 1977).
W	W	Asian catfish	Stomach	Loss of pepsinogen granules from chief cells, disintegration of goblet cells, pyknosis of gastric glandular epithelium, desquamation of gastric mucosa (Sastry and Gupta, 1978a).
			Pyloric caecae	Erosion of mucosa at tips of villi and infiltration of inflammatory cells (Sastry and Gupta, 1978a).
W	W	Sapo	Intestine	Similar changes as in pyloric caecae above, including a catarrhal enteritis involving hyperactive mucus secretion; erosion of mucosa at tips of villi (Sastry and Gupta, 1978a).
			Rectum Liver	Erosion of mucosa at tips of villi (Sastry and Gupta, 1978a). Perilobular and centrilobular necrosis, depletion of hepatocyte glycogen, disarray of muralia, cirrhosis, and lipid deposition with infiltration of phagocytic inflammatory cells in vasculature and intercellular spaces (Sastry and Gupta, 1978a).
W	W	Lisa (<i>Mugil auratus</i>)	Intestine	Edema of lamina propria of villi, hyperchromasia of nuclei, and apical cytoplasm of mucosal epithelium (Gutierrez et al., 1978).
			Liver	Thinning and hyperchromasia of mucosal epithelium, disorganization of lamina propria (Establier et al., 1978a).
W	W	Robalo (<i>Dicentrarchus labrax</i>)	Gills	Proliferation of dilated vascular elements, vacuolar degeneration of hepatocytes and disorganization of muralia (Establier et al., 1978a).
			Intestine	Distal swelling of lamellar respiratory epithelium and desquamation (Establier et al., 1978b).
W	W	Robalo (<i>Dicentrarchus labrax</i>)	Liver	Nuclear depolarization and hyperchromasia of apical cytoplasm in mucosal epithelium accompanied by increased numbers of goblet cells and mucosal desquamation (Establier et al., 1978b).
			Kidney	Hepatocyte vacuolation and degeneration, congestion of capillaries (Establier et al., 1978b). Renal tubules with reduced lumina, vacuolized epithelium having depolarized nuclei and hypochromatic cytoplasm; retraction of glomerular tufts (Establier et al., 1978b).

Table 2.—Continued.

Contaminant	Exposure route	Species	Tissues affected	Lesions
CH ₃ HgCl ₂	W	Rainbow trout (fry and fingerlings)	Gills	Hypertrophy and hyperplasia of secondary interlamellar epithelium with ballooning degeneration, separation of respiratory epithelium from lamellae due to edema fluid, abnormally high mitotic index with abnormal mitotic figures, and desquamation (Wobeser, 1975a).
	D & IP	Rainbow trout fingerlings	Gills	Swelling and hyperplasia of lamellar respiratory epithelium with clubbing and fusion of lamellae, respiratory epithelial necrosis and separation (Wobeser, 1975b).
			Pseudobranch Posterior kidney	Swollen epithelium with occasional ballooning degeneration (Wobeser, 1975b). Slight swelling of parietal epithelium lining Bowman's capsules, dilation of renal tubules and Bowman's space, hydropic degeneration of tubular epithelium and scattered foci of tubulo-necrosis (Wobeser, 1975b).
	IP	Channel catfish	Liver	Periportal necrosis of exocrine pancreas and surrounding hepatocytes, desquamation of biliary epithelium into duct lumina, inflammatory exudate on surface of liver capsule (Kendall, 1977).
W	Lisa	Gills Stomach (tunica muscularis) Intestine Liver Kidney	Respiratory epithelial hyperplasia and desquamation (Establier et al., 1978a). Nuclear depolarization, cytoplasmic hyperchromasia, and desquamation of mucosal epithelium (Establier et al., 1978a). Degeneration of mucosal epithelium including hyperchromasia, vacuolation, and depolarization of nuclei (Establier et al., 1978a). Vacuolation of hepatocytes, proliferation and dilation of capillaries, disorganization of muralia (Establier et al., 1978a). Focal degeneration of tubule epithelium with hyperchromatic nuclei and constricted lumina containing finely granular material; proliferative glomerulonephritis (Establier et al., 1978a).	
NO ₂	W	Steelhead trout (<i>Salmo gairdneri</i>)	Gills	Hypertrophy, hyperplasia, and cloudy swelling of lamellar respiratory epithelium (Wedemeyer and Yasutake, 1978).
AgCl	W	Mummichog	Lateral line (cephalic extension) Olfactory organ	Necrosis of cuboidal cells lining canal but no effect on neuromast epithelium; infiltration of granular leukocytes in canal lumina, canal walls, and peripheral connective tissue (Gardner, 1975). Degeneration and necrosis of lining and sustentacular epithelium with cellular debris in lumina (Gardner, 1975).
Na ₂ HAsO ₄	W	Green sunfish (<i>Lepomis cyanellus</i>)	Liver	Ultrastructural changes in hepatocytes include presence of intranuclear and intracytoplasmic electron dense particles, proliferation of smooth endoplasmic reticulum, enlarged but fewer myelin figures, increased size and numbers of lipofuscin granules, and abnormally enlarged mitochondria (Sorensen, 1976).
NaAsO ₂	W	Bluegill	Gills Liver Ovaries Blood vessels	Lamellar telangiectasia (Gilderhaus, 1966). Fatty infiltration and focal necrosis (Gilderhaus, 1966). Cytoplasmic clumping and karyolysis of ova (Gilderhaus, 1966). Endothelial separation and subendothelial myositis (Gilderhaus, 1966).
ZnSO ₄	W	Goldfish	Adrenal cortex (interrenal cells)	Degeneration with irregular clumping of nuclear material and decrease in cell volume (Bromage and Fuchs, 1976).

¹The significance of these observations is doubtful since similar changes appeared in control fish.

Table 3.—Summary of pathological changes in tissues of fish resulting from exposures to various chemotherapeutic compounds or drugs. For "Exposure routes," W = water, D = diet, IP = intraperitoneal injection.

Chemotherapeutic agent	Exposure route	Species	Tissues affected	Lesions
Bradophen	W	<i>Salmo</i> sp.	Gills	Destruction of respiratory epithelium and hyperplasia of mucus goblet cells (Reichenbach-Klinke, 1975).
Copper sulfate	W	Various fishes (i.e., carp, trout, gudgeon)	Kidney	Dilation of renal tubules and necrosis of hematopoietic tissues (Reichenbach-Klinke, 1975).
			Liver	Increase in hepatocyte lipid (Reichenbach-Klinke, 1975).
Dipterex	W	Carp	Also see Table 2 Spinal cord	Swelling of lipid substance surrounding large nerve cells (Reichenbach-Klinke, 1975).
Emtrysidina	W	Carp	Kidney Integument	Damage to tubular epithelium (Reichenbach-Klinke, 1975). Hyperplasia of mucus goblet cells in epidermis (Reichenbach-Klinke, 1975).
Formalin	W	Rainbow trout	Gills	Severe hypertrophy of lamellar respiratory epithelium sometimes accompanied by desquamation, pyknosis, karyorrhexis, edema between epithelium and blood capillaries, and hemorrhage (Smith and Piper, 1972).
			Pseudobranch Adrenal cortex (interrenal cells) Spleen Kidney	Nuclear swelling and hypertrophy of epithelial cells (Smith and Piper, 1972). Hyperplasia and hypertrophy (Smith and Piper, 1972).
	W	Steelhead trout	Gills	Reduction of lymphoid tissue (Smith and Piper, 1972). Congestion of blood sinusoids, nuclear swelling, and hydropic degeneration of renal tubular epithelium (Smith and Piper, 1972).
	W	Spring chinook salmon	Gills	Increase in the number of immature erythrocytes and some hemolysis (Smith and Piper, 1972). Hypertrophy of respiratory epithelium characterized by cloudy swelling and hydropic degeneration with eventual necrotic changes of pyknosis and karyorrhexis at longer exposure periods; separation of respiratory epithelium from lamellar pillar cells (Wedemeyer and Yasutake, 1974). Similar degenerative changes as seen in steelhead trout, but less severe (Wedemeyer and Yasutake, 1974).
Hexa-ex	W	Carp	Integument	Partial destruction of epidermis (Reichenbach-Klinke, 1975).
Kanamycin	IP	Rainbow trout	Kidney	Degeneration of tubular epithelium (McBride et al., 1975).
Malachite Green	W	Various fishes, (i.e., carp, trout, gudgeon)	Integument, gills, gut	Slight inflammation of epithelial cells (Reichenbach-Klinke, 1975).
			Kidney	Pigmentous degeneration of tubular epithelium, and a decrease in tubular height with an increase in the nucleus-cytoplasm ratio (Reichenbach-Klinke, 1975).
Methylene blue	W or D (?)	Various fishes, (i.e., carp, trout, gudgeon)	Peripheral blood	Polycythemia which may be beneficial to convalescing fish (Reichenbach-Klinke, 1975).

Table 3.—Continued.

Chemotherapeutic agent	Exposure route	Species	Tissues affected	Lesions
Neguvon, Masoten	W	Various fishes (i.e., carp, trout, gudgeon)	Central nervous system	Swelling of non-staining surroundings of the nerve nuclei particularly in the brain and medulla (Reichenbach-Klinke, 1975).
Ozone	W	Rainbow trout	Gills	Severe hypertrophy and hyperplasia of respiratory epithelial cells resulting in lamellar fusion and eventual epithelial degeneration and necrosis (Wedemeyer et al., 1979).
			Peripheral blood	Polycythemia and increased numbers of immature erythrocytes (Wedemeyer et al., 1979).
Penicillin G procain, dihydrostreptomycin sulfate, oxytetracycline (mixture)	IP	Chinook salmon	Embryonal tissues	Teratomas on 0-15 percent (DeCew, 1972).
Sulfamethazine	D	Fall chinook salmon	Stomach Abdominal cavity Mesenteric vessels Pancreas, adipose tissue of pyloric caecae Liver Kidney	Gross swelling (Wood et al., 1957). Edema throughout (Wood et al., 1957). Necrosis of arterial walls (Wood et al., 1957). Marked edema (Wood et al., 1957). Minor degenerative changes in parenchymal cells (Wood et al., 1957). Minor degenerative changes in renal tubules; crystalline deposits of sulfamethazine in hematopoietic tissue (Wood et al., 1957). Severe renal damage (Reichenbach-Klinke, 1975).
Sulfonamides	D (?)	Various fishes (i.e., carp, trout, gudgeon)	Kidney	
Thiabendazole	W or D (?)	Carp	Liver Kidney	Hypertrophy of hepatocytes, swelling of intercellular spaces, and vascular congestion (Reichenbach-Klinke, 1975). Degeneration of hematopoietic tissue and presence of casts within renal tubule lumina (Reichenbach-Klinke, 1975).
Tobramycin	IP	Coho salmon	Kidney	Moderate to complete necrosis of proximal tubules (Schneider et al., 1980).
Yomesan	D	Carp	Kidney	Degeneration of hematopoietic tissue and increased pigment deposits (Reichenbach-Klinke, 1975).

Table 4.—Review of mycotoxins, plant derivatives, and other chemical compounds tested for carcinogenicity in various fishes and shellfishes (see Table 5).

Mycotoxins	Plant derivatives	Other chemicals
Aflatoxin B ₁ (AFB ₁)	Bracken (dry powder and methanol extract)	2-Acetylaminofluorine (2-AAF)
Aflatoxin B ₁ (ammoniated)		0-Aminoazotoluene (0-AAT)
Aflatoxin B _{2a} (AFB _{2a})	Cyclopropanoid fatty acids (CPFA)	Dimethylaminoazobenzene (DAAB)
Aflatoxin G ₁ (AFG ₁)	Cycad nut meal	β-Aminopropionitrile (β-APPN)
Aflatoxin M ₁ (AFM ₁)	Cycasin	Aminotriazole (ATA)
Aflatoxin Q ₁ (AFQ ₁)	Gossypol	Aroclor 1254
Aflatoxicol (AFL)	Ipomeanol	Benidine
Citrinin	Ipomeanone	Benzo(a)pyrene (BAP)
Ochratoxin A & B	Methylazoxymethanol acetate (MAMA)	7-12 Dimethylbenz(α)anthracene (DMBA)
Patulin		Carbazone
Rubratoxin A & B	Pyrrrolizidine (<i>Senecio</i>) alkaloids	Carbon tetrachloride (CCl ₄)
Strigmatocystine	(PA's)	Dichlorodiphenyltrichloroethane (DDT)
Versicolorin A		Dibutylnitrosamine (DBN)
		Diethylnitrosamine (DEN)
		Diethylstilbestrol (DES)
		Dimethylnitrosamine (DMN)
		Ethyl nitrosourea (ENU)
		Methylnitrosourea (MNU)
		3-Methylcholanthrene (MCA)
		N-methyl-N'-nitro-N-nitrosoguanidine (MNNG)
		N-nitrosomorpholine (NM)
		Nifurpirinol
		Tannic acid
		Thioacetamide
		Thiourea
		Urethane

Table 5.—Summary of histopathological changes reported in fish and shellfish experimentally exposed to various potential carcinogens (abbreviations are defined in Table 4). For "Exposure routes," W = water, D = diet, E = water exposure of embryonating eggs, T = topical application of carcinogen, IIM = implantation in musculature, IPC = implantation in peritoneal cavity, I = injected, IP = intraperitoneal injection, and IM = intramuscular injection.

Carcinogen	Exposure route	Species	Lesions
Mycotoxins			
AFB ₁	D	Guppy ¹ (<i>Lebistes reticulatus</i>)	Liver tumor (Sato et al., 1973).
	D & E	Rainbow trout (<i>Salmo gairdneri</i>)	Liver tumor (Halver, 1967; Lee et al., 1968, 1971; Sinnhuber et al., 1968a,b, 1977; Wales et al., 1978; Hendricks et al., 1980a,c,f).
	W	Zebra fish (<i>Brachydanio rerio</i>)	None (Bauer et al., 1972).
AFB ₁ (in ammoniated corn)	D	Rainbow trout	None: Incidence of liver tumors reduced to levels in control diet (Brekke et al., 1977).
AFB ₁ (purified and ammoniated)	E	Rainbow trout	Liver tumors: Incidence same as with untreated AFB ₁ (Hendricks, unpubl.).
AFB _{2a}	E	Rainbow trout	None (Hendricks et al., 1980f).
AFG ₁	D & E	Rainbow trout	Liver tumors (Ayres et al., 1971; Hendricks et al., 1980f).
AFM ₁	D & E	Rainbow trout	Liver tumors (Hendricks et al., 1980f; Sinnhuber et al., 1974).
AFQ ₁	D	Rainbow trout	Liver tumors (Hendricks et al., 1980d).
	E	Rainbow trout	None (Hendricks et al., 1980f).
AFL	D & E	Rainbow trout	Liver tumors (Hendricks et al., 1980f; Schoenhard et al., 1981).
Citrinin	E	Rainbow trout	None (Hendricks, unpubl.).
Ochratoxin A & B	IP	Rainbow trout	Liver: Nuclear swelling and nuclear and cytoplasmic lipid vacuolation of hepatic parenchyma (Doster et al., 1972). Kidney: Necrosis of hematopoietic tissue, glomeruli, and proximal tubules in addition to cast formation and lipid vacuolation in renal tubules (Doster et al., 1972).
	E	Rainbow trout	None (Hendricks, unpubl.).

Table 5.—Continued.

Carcinogen	Exposure route	Species	Lesions
Patulin	E	Rainbow trout	None (Hendricks, unpubl.).
Rubratoxin A & B	E	Rainbow trout	None (Hendricks, unpubl.).
Sterigmatocystine	E	Rainbow trout	Liver tumors (Hendricks et al., 1980e,f).
Versicolorin A	E	Rainbow trout	Liver tumors (Hendricks et al., 1980e,f).
Plant derivatives			
Bracken	D	Guppy	Intestinal hyperplasia (Matsushima et al., 1975).
CPFA	D	Rainbow trout	Liver tumors (Sinnhuber et al., 1976; Hendricks et al., 1980c). Promoter of liver tumors (Lee et al., 1968, 1971; Hendricks et al., 1980c,d; Schoenhard et al., 1981).
Cycad nut meal	D	Zebra fish	Liver tumors (Stanton, 1966).
Cycasin	W	Guppy	Acute degenerative changes in liver (Stanton, 1966).
Gossypol	D	Rainbow trout	Liver foci of fatty change with bizarre nuclei and hepatocellular regeneration, necrosis of hepatocytes around bile ducts, and inflammation of periductal tissue (Herman, 1970). Kidney: Thickened glomerular basement membrane and presence of casts and melanin in tubule lumina (Herman, 1970). Pyloric caecae: Thickening of tunica propria due to inflammation (Herman, 1970). Generalized deposition of ceroid pigment in liver, kidney, and spleen (Herman, 1970).
Ipomeanol	E	Rainbow trout	None (Hendricks, unpubl.).
Ipomeanone	E	Rainbow trout	None (Hendricks, unpubl.).
MAMA	W	Medaka (<i>Oryzias latipes</i>)	Liver tumors (Aoki and Matsudaira, 1977, 1980).
PA's	D	Rainbow trout	Liver: Megalocytosis, intense eosinophilia, nuclear aberrations, microdroplet fatty change and necrosis in hepatocytes with focal hepatocyte regeneration. Extensive fibrosis in hepatic parenchyma and veno-occlusive disease in the centrolobular and hepatic veins were also present (Hendricks et al., 1981a). Kidney: Thickened glomerular basement membranes at higher doses (Hendricks et al., 1981a).
Other chemicals			
2-AAF	D	Guppy	Liver tumors (Sato et al., 1973; Pliss and Khudoley, 1975).
	D	Rainbow trout	Liver tumors (Halver, 1967).
	D	Zebra fish	Liver tumors (Pliss and Khudoley, 1975).
O-AAT	W & D	Guppy	Adenomatous hyperplasia in liver (Kimura and Kubota, 1972) and liver tumors (Khudoley, 1972; Pliss and Khudoley, 1975).
	D	Rainbow trout	Liver tumors (Halver, 1967).
	D	Zebra fish	Liver tumors (Pliss and Khudoley, 1975).
DAAB	D	Bitterling (<i>Rhodeus amarus</i>)	Degenerative changes in liver (Ermer, 1970).
	W & D	Guppy	Bile duct hyperplasia (Kimura and Kubota, 1972) and liver tumors (Khudoley, 1972; Pliss and Khudoley, 1975).
	D	Rainbow trout	Liver tumors (Halver, 1967).
	D	Stickleback (<i>Gasterosteus aculeatus</i>)	Degenerative changes in liver (Ermer, 1970).
	IIM & IPC	Stickleback	No tumors (Ermer, 1970).
	D	Zebra fish	Liver tumors (Pliss and Khudoley, 1975).
β-APPN	E	Medaka, <i>Anoptichthys jordane</i> , <i>Trichogaster trichopterus</i> , <i>Aequidens portalegrensis</i> , goldfish (mixed breed)	All species developed ecchordoma-like growths (Levy, 1962).
ATA	D	Rainbow trout	No tumors (Halver, 1967).
Aroclor 1254	D	Rainbow trout exposed to AFB ₁ as embryos	No increase in incidence of liver tumors (Hendricks et al., 1980a).
	D	Rainbow trout (brood females prior to spawning)	Promotes increase in liver tumor frequency in progeny following embryo exposure to AFB ₁ (Hendricks et al., 1981b).
Benzidine	D	Guppy	Severe toxic effect with focal necrosis, fatty change and hyperplasia of hepatic parenchyma (Pliss and Khudoley, 1975).
BAP	T	Bitterling	Epithelioma (Ermer, 1970).
	T	Carp (<i>Cyprinus carpio</i>)	No tumors (Ermer, 1970).
	I	Stickleback	No tumors (Ermer, 1970).
	T	Stickleback	Epithelioma (Ermer, 1970).
DMBA	IP, TM, IPC, T, D	Guppy	None (Pliss and Khudoley, 1975).
	W	<i>Poeciliopsis lucida</i> <i>P. Monacha</i>	Liver tumors (Schultz and Schultz, 1981).
Carbarzone	D	Rainbow trout	Liver tumors ² (Halver, 1967).
CCI	D	Rainbow trout	Liver tumors ² (Halver, 1967).
DDT	D	Rainbow trout	Liver tumors (Halver, 1967; Hendricks, unpubl.).
DBN	E	Rainbow trout	None (Hendricks et al., 1980f).
DEN	W	Guppy	Liver tumors (Khudoley, 1971, 1973; Pliss and Khudoley, 1975).
	W	Medaka	Liver tumors (Ishikawa et al., 1975).
	E	Rainbow trout	Liver tumors (Hendricks, unpubl.).
	W	Zebra fish	Liver tumors (Stanton, 1965; Pliss and Khudoley, 1975).
	D	Rainbow trout	Liver tumors ² (Halver, 1967).
DES	D & W	Guppy	Liver tumors (Khudoley, 1971, 1973; Sato et al., 1973; Pliss and Khudoley, 1975).
DMN	D & E	Rainbow trout	Liver tumors (Halver, 1967; Grieco et al., 1978; Hendricks et al., 1980f; Kimura et al., 1981a).
	W	Zebra fish	Liver tumors (Pliss and Khudoley, 1975).
	W	Freshwater mussel (<i>Unio pictorum</i>)	Degeneration and focal necrosis of tubular epithelium in the digestive gland followed by epithelial hyperplasia and neoplastic transformation; multifocal accumulations of hemocytes in vesicular connective tissue of the gills, gonads, and digestive gland (Khudoley and Syrenko, 1977, 1978).
	W	Bay mussel (<i>Mytilus edulis</i>)	Congestion of visceral and branchial vasculature accompanied by a thickening of vessel walls from deposition of a collagen-like material; severe alteration of normal branchial architecture by congested vessels and hemocyte infiltration of ciliated gill epithelium; loss of frontal and laterofrontal cilia from gill epithelium; diffuse infiltration of hemocytes in vesicular connective tissue and formation of occasional discrete hemocyte granulomas with central areas of necrosis; vesiculation and atrophy of digestive tubular epithelium with tubular necrosis in areas adjacent to hemocyte infiltration (Rasmussen, 1982).
ENU	E	Rainbow trout	None (Hendricks et al., 1980f).

Table 5.—Continued.

Carcinogen	Exposure route	Species	Lesions
MNU	W	Platyfish/swordtail (<i>Platypoecilus variatus</i> / <i>Xiphophorus helleri</i>)	Fibrosarcomas and rhabdomyosarcomas (Schwab et al., 1978).
MCA	T	Bitterling	Epithelioma (Ermer, 1970).
	T	Carp	No tumors (Ermer, 1970).
	T	Stickleback	Epithelioma (Ermer, 1970).
MNNG	E	Rainbow trout	Liver tumors, kidney tumors, air bladder adenomas (Hendricks et al., 1980b,f; Kimura et al., 1981a); inhibited maturation and tumors of the gonads, stomach adenomas, and abnormal pigmentation of the skin (Kimura et al., 1981a).
NM	W	Guppy; Zebra fish	Liver tumors and intestinal adenocarcinomas. Poorly differentiated fibrous lesion in abdominal cavities of zebra fish (Pliss and Khudoley, 1975).
Nifurpirinol	W	Croaker (<i>Nibea mitsukurii</i>)	Chromatophoromas (Kimura et al., 1981b).
Tannic acid	D	Rainbow trout	Liver tumors ² (Halver, 1967).
Thioacetamide	D	Rainbow trout	No tumors (Halver, 1967).
Thiourea	D	Rainbow trout	Liver tumors ² (Halver, 1967).
Urethane	D	Rainbow trout	Liver tumors ² (Halver, 1967).

¹A review of carcinogenesis in aquarium fish through 1975 is presented by Matsushima and Sugimura (1976).

²Doubtful significance, particularly in examples where massive concentrations of a compound have been used, since tumor frequency is low (5-29 percent) and not dose responsive.

(Continued from page 2.)

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