Review of the Literature
regarding the
Effects of Water Pollution on Freshwater Fish

by

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General Aspects of Water Pollution as Related to Fish

In an illustrated article Thomas (156) reviewed the literature on the effect of river pollution on fish and discussed the effects of toxicants, suspended solids deoxygenation, non-toxic salts, and temperature. He also presented information on the parasitic and other diseases of fish.

Wheeler (164) traces the decline of the fisheries of the Thames because of pollution. Considerable commercial fisheries that had existed in the tidal waters of the river have disappeared. Recent measures to control pollution have resulted in a partial recovery of the river. Forty-one species of freshwater and estuarine fish were taken in 1967 to 1968. There is evidence the migrating fish have been able to penetrate the worst polluted areas of the Thames into relatively clean waters upstream.

On the other hand, Cross and Braasch (37) found a rapid deterioration of the fish populations in the Neosho River, Kansas between 1952 and 1967. The species diversity had declined the most in areas in which fishkills due [redacted] to pollution from cattle feed lots had been common. Five species of fish common in 1952 could no longer be found at any station on this river.

David (41) discusses the factors causing deterioration of fisheries in Lake Bourget, France. These include pollution from the industrialized urban areas adjacent to the lake. Improved sewage treatment has not halted the eutrophication of the lake and the occurrence of algal blooms.

Armstrong, *et al.* (8) showed the applications of the species diversity index and the diurnal curve in evaluating the effect of pollution on the ecology of certain Texas rivers.

McDonald and Schmickle (105) reported on a winter fishkill in the Coralville reservoir in Iowa. Winter rains washed water which had a high oxygen demand into the reservoir. Ice cover prevented reaeration until warm weather melted the ice.

Gunning and Berra (62) observed the repopulation by fish in two experimentally decimated segments of a stream. In one area, Talisheek Creek, the repopulation group [redacted] was greater than the original population. In Bayou LaCombe, the new population was only 52% by weight of the original population.

A method is described by van Benden and van Benden (14) which was used to clean the bottoms of trout streams which had become silted as a result of pollution. Sacks of chalk were placed [redacted] in waters where the current was not [redacted] strong. The chalk washed out of the sacks gradually and deposited on the silt which covered the bottom. The condition of the stream improved in 6 to 8 weeks and the fish regained their vitality. Chalking was to be continued until the original source of pollution was controlled.

Water Quality Parameters and Dissolved Oxygen

Williams (166) studied the water quality parameters which affect survival of sockeye salmon from the egg to the adult stage. The water quality of the Fraser River (British Columbia) watershed appeared to be good and no toxicants in the form of heavy metals, herbicides, pesticides, or detergents were observed at lethal concentrations. A delay in the development of salinity preference and tolerance relative to the onset of seaward migration is suggested as a possible factor that can be correlated with the variation in marine survival of sockeye smolts.

Singh, *et al.*(142) conducted a series of laboratory experiments to study the effect of water temperature, turbidity, pH, D.O., total alkalinity, salinity, NH_3, chlorides, and sulfides on grass carp and silver carp. The young of both species tolerated a fairly wide range of all of the above parameters.

Craigie (36) observed that rainbow trout reared in soft water showed greater resistance to thermal stress than a group reared under identical conditions but in hard water. The difference in thermal resistance was not associated with experience in the early developmental period of the fish but with the period after the absorption of the yolk sac.

A study on the effects of various halides and water hardness in the survival of rainbow trout was reported by Hilden (75). Fish were able to tolerate "harder" water in the presence of sodium bromides, sodium chloride, sodium fluoride, and sodium iodide since their requirements for calcium were greater in the presence of increased concentrations of sodium halides. There was evidence the sodium fluoride was directly toxic but the mortality due to the other halides was due to osmotic changes.

Lloyd, et al (99) presented a review of the published and unpublished data on both the direct and indirect effects of extreme pH values on fish with an emphasis on European species. Among the conclusions that could be reached was that there is no definite pH range within which a fishery is unharmed and outside of which it is damaged, but rather there is a gradual deterioration as the values are further removed from the normal range. Between pH of 5 and 9 there is no direct lethality, however, the toxicity of some toxicants like NH_3 and cyanide is markedly affected by pH changes within the range. In general, more fisheries problems are observed in the acid range than on the alkaline side of the pH range.

Hartman and Gill (68) observed that neither pH nor total dissolved solids appeared to affect the distribution of juvenile steelhead and cutthroat trout. The effect of various chemicals on the activity of brook trout was studied in the laboratory by Dandy (39). Exposure to low D.O. concentrations, or to high concentrations of sulfides, chlorine, nascent oxygen, and copper was followed by significant increases in activity, particularly in the first two hours but the response returned to normal within 24 hours. Only for chlorine was the threshold concentration that induced a response within the lethal range. Fish transferred to freshwater recovered rapidly from the effects of low oxygen concentration and sulfides but recovery was not possible after relatively short exposures to chlorine, nascent oxygen, or copper.

Elliott (50) determined the oxygen requirements of chinook salmon and the variables which affected their oxygen requirements. These variables included water temperature, fish size, and activity. The data obtained could be used to calculate the amount of water of known D.O. needed to maintain an adequate oxygen supply.

Lowe, _et al._ (103) studied the tolerance to low oxygen concentrations of 4 species of freshwater fish native to the southwestern United States. _Cyprinodon macularius_ was the most tolerant to low D.O. Nikol'skaya, _et al_ (125) found that cell division in fish eggs (_Misgurnus_) could be stopped after 85 - 90 minutes in water at 19°C that was devoid of oxygen.

Amend, _et al._ (5) determined the influence of water temperature, D.O., hardness, and chloride ions on the sensitivity of rainbow trout to ethyl mercury phosphate (EMP). The death rate increased with an increase in water temperature, a decrease in D.O., and an increase in chloride ions. Calcium concentrations had no effect.

Eddy (47) experimented on the effect of different salinities on developing salmon eggs. In 100 per cent seawater, development was completely inhibited; at 50 per cent seawater, development occurred but no eggs hatched; and at 25 per cent, the eggs hatched but many of the larvae were deformed. Twelve and a half per cent salinity, which can be obtained in an estuary or which might result from brine pollution, is regarded as detrimental to developing fish eggs.

Domestic Wastes

A biological survey was conducted on two backwaters of the Bow River, one above and the other below the discharge of domestic and industrial wastes from the City of Calgary (93). Biological and chemical data indicated the following changes in the environment: Reductions in the kinds of invertebrates comprising the bottom fauna; increased condition factor of suckers taken at the downstream stations; and changes in the chemical parameters. Parasitological surveys indicated a reduced incidence of internal parasites suggesting that the vectors were unable to survive in the polluted reaches of the river. Janicke and Ludemann (81) observed that the effluents from activated sludge plants treating synthetic detergents was toxic to fish. [redacted] Free ammonia was present in the effluent. Reduction of toxicity was achieved by acidifying the effluent to pH 6.5. Chatterjee, et al, (31) studied the survival and growth of Catla and Labeo in a lagoon receiving diluted untreated sewage over a two-year period. High nutrient levels and the predominance of phytoplankton over zooplankton prevailed.

Detergents

Marchetti (112) reported that the toxicity of surface active agents is not dependent on the reduction in surface tension but depends on the temperature, ionic composition, and pH of the diluent water, as well as chemical structure, ionic character, and biodegradability of the individual agent. Gloxhuber and Fischer (58) observed that fish in lethal concentrations of alkylpolyglycol ethers which are nonionic detergents, exhibit a pattern of intoxication different than that displayed by fish held in lethal solutions of anionic detergents. The reduction in the surface tension of the water seems to be the cause of poisoning of fish by anionic detergents. This applies also to the alkylpolyglycol ethers, but while the action of anionic detergents is limited to the gills, alkylpolyglycol ethers pass through the gills and are absorbed. The symptoms of poisoning after absorption of alkylpolyglycol ethers show a marked similarity to those caused by tetracaine and procaine.

The comparative effects of alkylbenzenesulfonates and of linear alkylate sulfonate on the mosquito fish was studied by Dooley (44). ABS is more toxic than LAS. Nine-week old fish succumbed in a shorter period of time than did older fish and females consistently withstood concentrations that were lethal to males. The gills of fish killed by the detergents show severe damage.

Industrial Waste

Katz (84) reviewed the literature on the ecological effects of acid mine drainage waters in the Appalachian regions of the United States. Among the sources reviewed was the well-illustrated study of Boccardy and Spaulding (19) who observed the ecological effects of strip and surface mining on the fish and wildlife resources in eight Appalachian states. More than 9,000 miles of Appalachian streams are affected by acid mine waters as well as silt and sediments.

Parsons (126) reports on the effects of acid strip mine effluents in a Missouri stream. He studied the response of the animal community during non-polluted conditions, during pollution by acids, and during the recovery period. Fish populations were the most greatly affected.

Blakeley (18) observed the improvement in Little Scrubgrass Creek which is affected by acid waters from an abandoned strip mine. A lime neutralization plant has allowed fish, including trout, to flourish for several miles downstream from the source of pollution.

Moore and Kin (120) reported on a kill of cattle and fish in Buck Creek, Indiana following a train wreck which allowed a spill of acetone cyanohydrin into the creek. This substance de- composes into acetone and HCN. Some fish were killed at HCN concentrations as low as 0.03 mg/l. Measures taken to reduce the effects of the spill were outlined.

Metallurgical and metal working industries discharge wastes including rust, oil, resins, arsenic, and phenols into waters of the Dnieper Basin ([illegible] -(46). These wastes affect the commercial fish species by reducing their food organisms. Scharf (138) describes the adverse effects of cotton dye wastes on the flora and fauna of the River Spree.

The long range toxicity to killifish of a water soluble kyanizer containing sodium fluoride and the sodium salt of dinitro-ortho-cresol was determined. Dinitro-ortho-cresol was most toxic to fish but the addition of sodium fluoride increased its toxicity (12).

Graham and Dorris (39) conducted a long term continuous toxicity bioassay of oil refinery effluents. Fish were adversely affected by extended exposure to subacute concentrations of effluents with initial low toxicity.

A team of Japanese (119) studied the biological effects of industrial and domestic wastes on two adjacent rivers. One river received wastes from slaughter houses and tanneries and the other wastes from a titanium factory. The reduction in the number and kinds of the various fish species is described.

Pulping Wastes

Waste waters from wood hydrolysis plants are highly toxic to aquatic organisms (98). Of three organisms tested with these wastes, *Daphnia*, *Cyclops*, and *Gammarus*, the latter was the most sensitive. All of the organisms died after 50 minutes in undiluted treated waste waters and within a few days in a 1:10 dilution.

Sprague and McLeese (150,151) in a series of studies determined that 12% to 15% of neutralized bleached kraft pulping effluent for Atlantic salmon was the threshold of toxicity in freshwater. Larval lobsters, *Homarus*, are fairly tolerant and concentrations below 10% did not greatly affect their survival in seawater. Adult lobsters in seawater are more resistant than lobster larvae or salmon parr. Bleached kraft pulping effluent have at least two different toxic materials. Stored under sterile conditions, these wastes lost much of their toxicity for salmon parr in one week and all of the toxicity in two weeks but lost little toxicity to lobster larvae in two weeks. Biological oxidation of the wastes for one week eliminated toxicity for salmon parr but did not greatly change toxicity for lobster larvae.

Das, *et al*. (40) indicated that tetrachloro-o-benzoquinone was involved in the toxicity of bleached kraft effluent to fish. This substance is toxic to Atlantic salmon at low concentrations.

Heavy Metals

Brungs (22) conducted a continuous flow bioassay for a period of ten months to determine the effect of zinc on minnows. Reproduction was almost totally inhibited at zinc concentrations that had no effect on survival, growth, and maturation. At the same concentrations there was no effect on survival of fertilized eggs and larvae that had been obtained from ~~other~~ fish that had not been exposed to zinc. Rachlin and Perlmutter (130) maintained rainbow trout gonad cells in the laboratory and tested them in various concentrations of zinc sulfate. At 32.0 mg/l zinc, mitosis was completely inhibited after 96 hours. At 18.0 mg/l of zinc, destructive changes in the cell structure were observed. Rachlin and Perlmutter (129) observed the response of platyfish and the fathead minnow to zinc solutions. Sprague (148) noted that rainbow trout showed strong avoidance reactions to sublethal concentrations of zinc sulfate. The threshold avoidance level was 5.6 ug/l of zinc which is only 0.01% of the lethal threshold concentration. Brown, et al. (21) studied the toxicity to rainbow trout of various concentrations and mixtures of ammonia, phenol, and zinc. When zinc was over 70% of the mixture, some possible antagonistic effects were observed. Chen and Selleck (32) used zinc ion and cyanide as toxicants to model the kinetic rates of the toxication and detoxication reactions as a function of parameters measurable in the standard fish bioassay with the subsequent computation of the threshold concentration. A function was also developed for the definition of combined toxicity in terms of concentration of the individual toxicants.

Sprague (149) found that tri-na-nitrilotriacetate - H_2O markedly reduced the toxicity of copper and zinc ions to trout. After extensive tests, Sprague suggested the use of the chelating agent as a temporary treatment for a spill of these metals which might affect a valuable stream area.

The maximum acceptable concentration of copper for the fathead minnow was determined by Mount and Stephan (122) to be between 0.13 and 0.22 of the 96-hour TL_m. This was for water of an EDTA hardness of 30 mg/l as $CaCO_3$. In an earlier study with water of an EDTA hardness of 200 mg/l, the application factor was between 0.03 and 0.08 of the 96-hour TL_m.

Copper and zinc pollution in the Miramichi River plus high water temperatures were involved in an epizootic by the bacteria <u>Aeromonas liquefaciens</u>. Atlantic salmon and suckers were affected by the disease (127).

Shabalina (141) added small amounts of cobalt chloride to the food of rainbow trout. Changes in the distribution of fat in the bodies of two-year old fish were observed and the experimental fish were also [redacted] more tolerant to increased water temperatures.

Seth, et al. (140) determined the toxicities of arsenic, cadmium, hexavalent chromium, cyanide, lead, and selenium to fish in constant flow bioassays. The TL_m's determined were all higher than the maximal permissible concentrations for drinking water and fish, therefore, were not judged suitable for monitoring domestic water supplies.

Pesticides

Several papers have reported on the extent of pesticide contamination in the environment. The U. S. Bureau of Sport Fisheries (1) gave data obtained in a two-year monitoring survey. DDT in concentrations up to 45 mg/l was found in 584 of 590 samples which included 62 species of fish taken from 45 rivers and lakes across the United States. The presence of DDT and DDE in fish, penguins, skuas, and seals taken in the Antarctic was reported by George and Frear (55). Stout (153) described a program for monitoring the DDT, DDE and TDE residues in fish of the Northeast Pacific Ocean. Fish were collected in all of the major watersheds in Massachusetts and analyzed for DDT, DDE, and DDD by Lyman, et al. (104). DDT residues ranged from zero to 49.10 mg/L. Linn and Stanley (97) determined TDE residues in Clear Lake fauna from 1959 through 1965. A decrease in TDE residues from 1958 to 1963 and 1965 was observed.

Hunt and Keith (79) give some background information on the effects of [redacted] pesticides on [redacted] fish and wildlife. Some methods used in field and laboratory investigations and the interpretation of results are reviewed.

Mount and Boyle (121) found that the concentration of parathion in catfish blood and in the surrounding water is closely related and can be used to predict death due to acute toxicity. The sources of error resulting from using fish brain acetylcholinesterase activity as an indicator of parathion pollution were discussed by Gibson, et al.(56).

Several papers reported the effects of pesticides on an ecosystem. Hickey, et al. (74) studied organochlorine residue levels in mud samples, amphipods, alewives, whitefish, ducks, and gulls in the Green Bay of Lake Michigan. Biological magnification of DDT and its metabolites was noticed as one goes up the food chain, with the body fat of herring gulls averaging 2441 mg/l. A river basin study by Nicholson, et al. (124) showed that coagulation, sedimentation, rapid sand filtration, chlorination, and adjustment of pH were effective in reducing the concentrations of DDT and DDE but not of toxaphene and benzene hexachloride.

The effects of insecticides upon reproduction or the reproductive potential of fish have been studied by many researchers. Solly and Ritchie (145) reared rainbow trout eggs from 5 different lakes in New Zealand. Egg viability was correlated with DDT residue levels. TEPA, an insect chemosterilant, was tested by Stock and Cope (152) with the guppy to determine its effect on reproduction. They concluded that male fertility was more readily affected than was female fertility. Histological examination showed that only the testicular tissue was affected by [redacted] TEPA. [redacted]. A study by Konar (89) of the lethal effects of the organo-phosphorus insecticide, DDVP, on the eggs and hatchlings of *Channa punctatus* showed that above 1.6 mg/l, DDVP lowered hatching success, increased hatching time, and inhibited yolk absorption. In another work, Konar (90) studied DDVP and phosphamidon as selective toxicants.

Bender (15,16) studied the uptake and retention of malathion by the carp. Highest malathion concentrations were found in the liver followed by the flesh, blood, gills, and brain. The average half-life of the residue in tissues was calculated to be 12 hours.

The toxicity of parathion and potassium cyanide to guppies was determined by Nagasawa, *et al*. (123). Rao, *et al*. (132) determined the toxicity (LD_{50}) [redacted] of endrin, DDT, methyl parathion, malathion, and benzene hexachloride to *Puntius puckelli*.

The physiological effects of DDT on fish have been the subject of much study. Macek (106) found that underyearling brook trout fed 2 mg DDT per kg fish per week for 31 weeks gained more weight than fish on a DDT-free diet. When these groups of fish were starved, the mortality was many times higher in the fish on the DDT diet. When Anderson and Peterson (7) exposed brook trout for 24 hours to sublethal doses of DDT, the cold-blocking temperature for a simple reflex is altered in a way suggesting that DDT is affecting the thermal acclimation mechanism. Anderson (6) reported that exposure of brook trout for 24 hours to DDT (0.10 - 0.30 mg/l) renders the lateral line hypersensitive to the experimental stimulus. The chronic oral DDT toxicity in juvenile coho and chinook salmon was studied by Buhler, et al. (23). They found that chinook salmon were 2 - 3 times more sensitive than coho, that toxicity was directly related to fish size, that liver size decreased, and that carcass lipid content increased as a result of exposure to DDT.

Aubin and Johansen (10) exposed goldfish to 1 mg/l DDT for 2.5 hours and found they experienced a complete loss of equilibrium and a 50% mortality within 10 hours. DDT was shown to affect the spontaneous electrical activity of the cerebellum. Rainbow trout larvae exposed to the organophosphate insecticide, Dylox, in concentrations of 5 mg/l and 100 mg/l were observed by Matton and Laham (117) to undergo abnormal behavior. This was associated with acetylcholinesterase inhibition. Histopathological examination showed changes in the heart, liver, blood cells, pseudogills, and muscular tissues.

The effects of temperature on the susceptibility of bluegills and rainbow trout to 15 pesticides were studied by Macek, et al. (107). Increasing temperature increased susceptibility. They postulated a higher pesticide uptake and increased enzymatic activity with increased temperatures.

Hashimoto and Fukami (69) determined the toxicity of various insecticides, fungicides, and herbicides applied orally and topically to carp. The oral route exhibited lower toxicity than the contact method.

The effects of various toxicants on community photosynthesis and respiration were determined by Whitworth and Lane (165). DDT, antimycin A, and $KMnO_4$ resulted in simultaneous increases or decreases in both community photosynthesis and respiration. Formalin, nigrosine black, malachite green, Diquat, and $CuSO_4$ (in various concentrations) usually depressed oxygen production and increased respiration.

Hatfield (71) studied the effects of a DDT larviciding program on aquatic fauna in a Labrador stream. Losses of brook trout, reductions in bottom invertebrate populations, and increases in the numbers of drifting insect larvae were associated with DDT application. Burdick, et al. (24) discussed the use of methoxychlor as a blackfly larvicide, and the persistence of its residues in fish and its effect on stream arthropods.

Fromm and Hunter (54) demonstrated the transfer of dieldrin from environmental water into the isolated perfused gills of rainbow trout. Chadwick and Brocksen (30) studied the uptake rate of dieldrin (HEOD) from contaminated water or food by *Cottus perplexus*, tubificid worms and *Chironomidae*.

During the past year several studies were made of pesticide-resistant fish populations. Culley and Ferguson (38) tested the resistance of insecticide-resistant mosquitofish to 28 insecticides. Results indicated that resistant mosquitofish have developed high resistance only to the toxaphene-endrin related insecticides. Studies by Burke and Ferguson (25) revealed that the toxicity of DDT, toxaphene, and endrin is greater in flowing than in static systems. The merits of static and flowing tests are presented. Ferguson (52) discusses the nature of genetic mechanisms responsible for resistance, and the possible hazards that resistant populations of fish pose to the food web and to humans.

Great concern over the deleterious effects of pesticides upon the environment has been expressed. Heinisch (73) listed possible methods by which organisms may be protected. Substitution of persistent chlorinated hydrocarbon pesticides by less persistent compounds is suggested. Ramade (131) discussed the pollution of the oceans by chlorinated hydrocarbon pesticides and the possible deleterious effects on aquatic fauna. He lists alternatives to the persistent pesticides.

Saunders (137) describes the mass mortalities and abnormal behavior of brook trout and Atlantic salmon resulting from accidental spillage of nabam and endrin. The capacity of sheepshead minnows to avoid 6 pesticides was investigated by Hansen (67).

Cherrington, *et al.*(33) reported on the degradation of DDT to TDE by the intestinal microflora in Atlantic salmon. The detoxification of pesticidal residues in fish and shellfish was discussed in a thesis by Hallab (64).

Herbicides and Miscellaneous Toxicants

Alabaster (3) reported on the survival of fish in 164 herbicides, insecticides, fungicides, wetting agents, and miscellaneous substances. The toxicity of nine therapeutic and herbicidal compounds to striped bass was determined by Wellborn (163) by 96-hour toxicity bioassays. Trzebiatowski (158) investigated the toxicity of liquid Antyperz and a mixture of Antyperz and Pielik to one and two-year-old carp. Under the experimental conditions, these herbicides were shown to reduce the number of water plants and yet not harm carp. The TL_m of Diquat and Dichlobenil to six species of pond invertebrates were determined by Wilson and Bond (168). Abedi and Scott (2) investigated the effects of 14 fungal toxins on the larvae of zebra fish. Sterigmatocystin, gliotoxin, and aflatoxin B_1 were the most toxic, being lethal at concentrations of less than 1 μg/ml.

Rainbow trout were used by Bauer, et al.(13) to determine the LD_{50} values of aflatoxins B_1 and G_1. The values were .81 mg/kg and 1.90 mg/kg for aflatoxin B_1 and G_1, respectively. Farrow (51) reported on fish mortalities caused by an extracellular fish toxin produced by the alga Prymnesium parvum.

Smirnova, et al. (143) determined the toxic effects of tolylenediamine and o-toluidine on guppies, some species of arthropods, and on Scenedesmus.

Berger, et al. (17) tested the toxicity of Antimycin A in water of various temperatures, hardness, pH, and turbidity to 31 species of freshwater fish of various sizes and life stages. Twenty-four species could not survive 5 ppb and only certain catfishes are able to survive 25 ppb. Antimycin was reported by Burress and Luhning (26) to be effective in controlling green sunfish and golden shiners in channel catfish ponds. Burress and Luhning (27) reported on another application of Antimycin as a selective toxicant. Finucane (53) discussed the treatment of a marine bay with Antimycin A. Members of 38 fish species were killed, while zooplankton and invertebrates were unaffected. Complete degradation of Antimycin occurred in 5 days. Additional work on Antimycin A as a fish toxicant was conducted by Gilderhus, et al. (57). A synergistic effect between Antimycin A and rotenone was detailed by Howland (76). Marking (113) determined the toxicity of rhodamine B and fluorescein and their compatability with Antimycin A. The 96-hour TL_m for rhodamine B ranged from 217-526 mg/l, whereas the TL_m value for fluorescein ranged from 1372-3433 mg/l. MacPhee and Ruelle (109) reported on the biological [redacted] selectivity of 1,1'-methylenedi-2-napthol. It is 3 to 100 times more toxic to squawfish than to salmonids.

Little lasting effect on the non-target species was noticed by Cook and Moore (34) on the Russian River following rotenone treatment in a rough fish control project.

Halsband and Halsband (65) determined the tolerance limits for aminotriazole of trout and Gammarus on the basis of [redacted] their metabolic rates and neurophysiological responses. Fish showed neurophysiological effects above 50 mg/l, whereas metabolic measurements showed a tolerance limit of 200 mg/l. Exposure of A. anguilla to sublethal concentrations (.01 and .1 mg/l) of fenitrothion for 24 hours was reported by Gras, et al. (60) to cause a significant decrease in brain acetylcholinesterase activity.

A group of toxicants of growing concern are the polychlorinated biphenyls (PCB). Risebrough, et al. (134) reported on the widespread contamination of the global ecosystem with polychlorinated biphenyls. The adverse effects of the biphenyls on reducing eggshell thickness and bird weight, and thus future bird populations, were stressed. The presence of PCB's in fish, mussels, and birds from the Rhine River and Netherland coastal area was reported on by Koeman, et al. (87).

Svendsen (154) presented an annotated bibliography containing 26 references on the biochemistry, physiology, and methods of analyzing methylpentynol. Marking (114) reported on testing methylpentynol in 96-hour bioassays for its toxicity to 9 fish species. LC_{50}'s ranged from 660 mg/l for lake trout to 1890 mg/l for channel catfish. The efficacy of methylpentynol as an anesthetic for [redacted] 4 salmonids was reported by Howland and Schoettger (77).

Locke (101) tested the effectiveness of quinaldine as an anesthetic for brook trout, lake trout and Atlantic salmon. He feels that it warrants wider use as a fish anesthetic. In 96-hour toxicity bioassays Marking (115) found that quinaldine was toxic to some trouts, pike, catfish, bass, bluegills, and walleyes. Toxic concentrations ranged from 2.0 to 25 mg/l. Schoettger and Julin (139) reported on the efficacy of quinaldine as an anesthetic for 7 species of fish. Anesthetic effects were influenced by pH and water temperature, but not by water hardness, age of quinaldine solution, or repeated exposure. Total loss of equilibrium within two minutes was obtained with 15-70 mg/l of the drug.

Wilson, _et al_. (167) determined the toxicity of ammonia to rainbow trout, channel catfish and goldfish. The trout were the most sensitive and goldfish the least sensitive. Increasing water temperature decreased the fishes' tolerance. Adding [redacted] urea [redacted] to a fish pond to serve as a nitrogen supplement was reported by Tasnadi and Vamos (155) to kill the fish when the pH of the water was above 8.6.

Asano, et al. (9) reported that a water temperature rise of 10° C doubled the toxicity of pentachlorophenol to carp. A study on the toxic effect of pentachlorophenol on shellfish in coastal waters was reported by Kobayashi, et al. (86).

Cope, et al. (35) described the effects of dichlobenil on a fish pond in Colorado and one in Oklahoma. Different effects were noticed in the two environments.

The lethal threshold concentration of the organic refrigerant, Santowax OM, to rainbow trout fry was determined by Guthrie and Acres (63) to be between 5 and 10 mg/l. Havelka and Albertova (72) studied the influence of antifreeze liquids and several aromatic compounds on *Daphnia*, *Tubifex*, and carp.

Ryback, et al. (136) determined the uptake and metabolism of ethanol by the goldfish. Ethanol entered the fish blood by passive diffusion and was metabolized at a rate of 275 mg/kg/hr. Tillander, et al. (157) studied the excretion of phenyl- and methylmercurinitrate following oral and intramuscular administration into fish, mussels, snails, and crayfish. The results indicated that part of the compounds are excreted rapidly, while excretion is slow after the mercuric compounds have become bound to the proteins.

Mitchum and Moore (118) reported success in using di-n-butyltin oxide to control the intestinal fluke *Crepidostomum farionis* in golden trout.

Manion (111) evaluated the efficacy as larvicides of Bayluscide and TFM. The population of lampreys in Saux Head Lake was reduced 89% by treatment with granular Bayluscide.

Methodology

To adequately gather information of the biological effects of water pollution, it is necessary to use both ecological and laboratory procedures. Toxicological studies will help evaluate the biological effects of wastes and will give data which will help establish useful treatment procedures and dilution ratios (110). Reith, et al. (133) studied the sensitivity of two groups of guppies to dieldrin. Three-day-old guppies were more sensitive than 21-day-old guppies. The writers used guppies as experimental animals to determine the toxicity of substances suspected of being toxic to humans and other animals. Cairns (28) stressed that research bioassay investigations be conducted in a manner that can be duplicated readily in other laboratories. Any deviations from standard procedures should be clearly indicated. Cairns, et al. (29) found that large variations in the concentrations of a toxicant (zinc) in a bioassay procedure in which fresh solution was added periodically to replace solutions, did not significantly change the toxicity of the solution to fish. Outside of the theoretical implications it might be noted by industrial operators that no substantial safety factor is introduced by temporary reductions in the concentration of toxicant in a waste effluent.

Klekowski and Kamler (85) describe a flowing water polarographic respirometer which was used to measure the changes in oxygen consumption by larval dragonflies in waters of various oxygen concentrations. Li and Jordan (96) as well as Rachlin and Perlmutter (128) used fish cell cultures to study the effects of aquatic toxicants. Li and Jordan (96) used L-cells to determine their sensitivity to several pesticides and herbicides. In the case of DDT, the inhibition of the L-cells was strictly concentration dependent.

Physiology and Pathology

Krueger, et al. (92) studied the effects of pentachlorophenol poisoning on the bioenergetics of exercise in fish. In cichlids an exposure to .2 mg/l pentachlorophenol caused an increase in food uptake and energy losses with a decrease in growth. In salmon there was a marked difference between performances of poisoned fish and controls in: 1) time before exhaustion, 2) distance traveled, 3) lipid loss, 4) weight loss, and 5) total caloric loss.

Dodgen and Sullivan (43) fed apholate (200-400 mg/kg) to channel catfish and found effects on the lymphocytes and thrombocytes. Infection of the skin was the primary symptom noted. No deaths occurred in less than 8 days regardless of dose.

Eller (49) investigated the pathological effects of Hydrothol 191, an N-dimethylalkylamine salt of endothal, on redear sunfish. Morphological changes occurred in the gills, liver, testes, and blood during the first 14 days of exposure to .3 mg/l Hydrothol. These changes were reversed gradually and the histological picture was [redacted] similar to that of the control fish after over 100 days in the .3 mg/l [redacted]. Fish exposed to .5 mg/l had precipitates in the blood vessels and posterior kidney.

Chronic poisoning with cyanide of coho salmon and of a cichlid was studied by LeDuc (95). The salmon were exposed to concentrations up to 0.08 mg/l of hydrogen cyanide for 24 days at 16° C; the cichlid was exposed for 36 days at 25° C to 0.008-.10 mg/l. Enzymatic action in [redacted] the liver and intestine were studied. There was some adaptation to cyanide and little weight loss occurred. Levels of 0.01 mg/l affected energy resources. A maximum permissible level of 0.04 mg/l in surface waters was recommended.

Studies by Konar (88) on the effects of heptachlor and nicotine on [redacted] catfish showed that the [redacted] barbels of the fish subjected to these substances developed lesions.

Sublethal concentrations of ammonia in the water cause an increase in urine excretion of rainbow trout. Lloyd and Orr (100) suggest that the fish is more permeable to water at these levels of unionized NH_3. Increases in temperature did not cause changes in urine production at constant NH_3 levels. Acclimation to NH_3 seemed to occur.

Loeb (102) has been working on the surfacing of fish due to chemical action of d-lysergic acid derivatives. He found that 36 of 48 derivatives caused surfacing of fish. The surfacing behavior was observed over a wide range of temperature and pH. The compounds were changed by ultraviolet light. Fish without airbladders were unaffected.

A method of post-mortem detection of nickel containing pollutants in fish has been developed [redacted] by Kariya, et al. (83). He used the dimethylglyoxime method to detect nickel in tissues.

Baker (11) studied the effects of three concentrations of copper, high, low and medium, in flounder using routine histological techniques and electron microscopy. Changes in tissue structure was observed in the liver, kidney, hemopoetic tissues and the gills. Electron microscopy showed changes not observable under light microscopy.

The massive dieoff of alewives in Lake Michigan, 1967, was studied by Brown (20). He found fish that died and samples from the living populations were similar in age and sex ratios. Evidence showed fish had been feeding up to death. Spawning attrition was eliminated as a cause of death. Hemorrhages were observed in the fish that died. No specific cause for the dieoff was determined.

Eddy and Morgan (48) made hematological measurements of the blood of rainbows acclimated to 40 mg/l and from 70 to 100 mg/l free CO_2. These measurements indicated that rainbow trout could acclimate to some extent to the high levels of CO_2.

Ruff and Zippel (135) observed oxygen absorption in Carassius auratus after changes in oxygen pressure. They found that oxidative metabolism was unchanged for moderate oxygen pressures, but increased when the pressure was increased or decreased. An increased breathing rate at low pressures caused an increase in metabolism.

Wittenberger (169) found that hypoxia and moderate effort induced anaerobic conditions in the white muscle of trout. The red muscle had great increases in glycogen. Exposure of the
Caused effects those produced by
trout to air [redacted] similar to hypoxia.

Spitzer, et al. (147) acclimated bluegill sunfish to 30°, 25°, and 13° C and exposed them to hypoxia. Bradycardia occurred at all temperatures. The ventilation rate increased at 13° and 25° C. The 30° C fish exhibited oxygen dependence.

Chemical composition of urine from rainbow trout following hypoxic stress was studied by Hunn (78). Post stress measurements showed an increase in urine output and increases in concentrations of Na, K, Mg, Cl, inorganic phosphate and lactate. Calcium concentrations dropped initially then increased above control values. All other constituents were approximately the same as those of the controls at 20 hours after stress.

Mason (116) placed coho salmon eggs under hypoxial stress prior to emergence. Those under stress were smaller and migrated sooner than unstressed fish. Success in competition for food and space in non-migrating fish was related directly to size. Early emigrants had less competition and grew more rapidly than those that remained longer in the gravel.

Swimming performance of goldfish and rainbow trout acclimated to 95% oxygen saturated water showed a sharp decrease when the oxygen level was decreased. Kutty (94) attributed this to an oxygen-sensing mechanism because swimming performance increased as soon as the oxygen level went up.

Grigg (61) implicates the inability of oxygen to be transported across gill membranes as the reason for deoxygenated arterial blood, at low ambient oxygen levels, in the brown bullhead. Thus ventilation rate is not the limiting factor in low ambient oxygen waters.

Whitespot disease in fry was shown to increase when the eggs had been stressed in shipping. Reduction of the disease occurred when the mineral content of the water, [redacted] was increased. Calcium chloride was the compound preferred for treatment of the water (108).

Albrecht (4) has shown the spleen and kidney to be full of blood at low levels of fish activity. These organs are used as reservoirs for blood and on nervous or hormonal demand, release blood to the muscles. They are temperature sensitive and do not function well after long exposure in 30° C water. These organs are good physiological indicators of the condition of the fish.

Miscellaneous Papers

Smith and Grigoropoulos (144) developed a bioassay procedure that can be used when the quantity of test material is limited. They conducted tests with this procedure on extracts of odorous surface and ground waters and on the pesticides Sevin and malathion. Extracts of both odorous surface and ground waters were toxic to fish in acute and long-term tests. Organics extracted from well water appeared to clog the fish gills while organics from spring water interfered with the internal respiratory enzyme system. Static bioassays were conducted by Krishnaswami and Kupchanko (91) to determine the relationship between petroleum refinery waste waters and tastes in rainbow trout. Taste panelists were able to correlate an oily taste in fish with the threshold odor number of the water in which the fish had been held.

Vallin (160) made a study to determine the toxic effect of fluorine on fish. Salmonids were more susceptible to fluorine poisoning in soft water than in hard water. It was concluded from these studies that no special treatment was necessary before the discharge of aluminum waste waters which contained fluorides into the Oresund. Vallin (161) discussed the effects of gypsum on fish in the Oresund. He concluded that the local turbidity caused by the discharge of gypsum water into the Oresund will not cause any noticeable damage to the fishery. The correlation between the iodine, manganese, and cobalt content of the water and fish of the upper Lena River was determined (42). The iodine content was related directly to that of the water but no such function was found for manganese. In both fish and water a linear relation between iodine and copper content was observed.

Sparks, *et al*. (146) studied the effects of treated ammunition wastes that were discharged into a Kansas Creek. The water contained sulfuric acid which had been neutralized with slaked lime. Twelve channel catfish kept in a synthetic waste which approximated that of the ammunition plant died within two days when a suspended solids concentration of 24,000 to 30,000 mg/l was maintained. Eleven of 12 catfish survived 22-28 days in synthetic wastes from which all settleable solids were removed.

Wedemeyer and Ross (162) demonstrated that coho salmon and rainbow trout were highly resistant to endotoxins from both *Escherichia coli* and *Aeromonas salmonicida*. It was concluded that the metabolic effects of bacterial endotoxins in salmonids were qualitatively different from those of the higher vertebrates.

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