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FISHES OF THE DETROIT RIVER, AND NOTES ON THEIR LIMITS OF TOLERANCE TO POLLUTANTS [1]

by

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This report contains a list of the species of fish which occur in the Detroit River, followed by a section dealing with the limits of tolerance of fish to various types of pollutants. The fish list most certainly is not complete, for probably there are quite a few species, mostly of rare occurrence in the river, which we have overlooked. The information on tolerance to pollutants has been compiled from the literature, mostly from the writings of M. M. Ellis, long-time investigator of water pollution for the United States Fish and Wildlife Service.

The sources of the present records on fish fauna and pollution tolerance are, in the authors' opinions, entirely dependable, and therefore, again in our opinion, the records have a high degree of reliability.

This report has been prepared for, and as the result of a request by, the International Joint Commission. Its dual purpose has been to present a general account of the kinds of fishes present in the area and the amount of pollution which fish will tolerate. In neither respect is the present

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[1] A contribution from the Institute for Fisheries Research, Ann Arbor.

report highly exhaustive.

The Michigan Stream Control Commission has supplied us with a list of the types of industrial wastes frequently encountered in the Detroit River.

THE FISH FAUNA OF THE DETROIT RIVER

Our fish records have been obtained from the following sources: The biennial reports of the Michigan State Fish Commissioners, various reports of the United States Bureau of Fisheries, extensive fish collections made by the University of Michigan Museum of Zoology during recent years, and creel census records collected by the Michigan Department of Conservation.

This general creel census consists of sport fishing records collected at random by the Conservation Officers during their routine checking of fishermen. These records are compiled by the Institute for Fisheries Research, a part of the same department. This general census has been in operation since 1928, and up to 1947 there are 15 years for which sport-fish records are available for the Detroit River.

These creel census data are summarized in an accompanying table, which shows that 18 different species of game and coarse fish have been recorded from this water by Conservation Officers. Yellow pikeperch (walleye), yellow perch, white bass, rock bass, and sheepshead have predominated in the catch. The composition by percentage of each of the above species, in respect to the total catch for the 15 years, is 30, 24, 13, 12, and 6 per cent, respectively.

The recent field collections by the Museum of Zoology, University of Michigan, are an especially valuable source of information on the fishes of the Detroit River. The most extensive of these collections were made on the lower, polluted section of the river, from June 19 to October 19, 1935, by Dr. Carl L. Hubbs, at that time curater of fishes in the Museum of Zoology,[2] University of Michigan, and I. A. Rodeheffer. Seining was done on the Detroit River from the mouth of River Rouge to about three-quarters of a mile

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[2] The records have been made available to us through the courtesy of Dr. R. M. Bailey, the present Curator of Fishes in that museum.

Table 1

General Creel Census Data from the Detroit River, 1928-1947

(Number of fish recorded for each species)

Year	Fishermen hours recorded	Smallmouth bass	Largemouth bass	Bluegill	Pumpkinseed sunfish	Rock bass	Crappie	Perch	Walleye	Northern pike	Bullhead	Carp	Common sucker	Redhorse	Sheepshead	White bass	Others*	All fish
1928	281	...	...	10	4	32	...	244	1	3	...	...	1	...	...	...	...	295
1929	18	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	2
1930							No Records											
1931	144	...	...	...	...	...	...	113	1	...	...	...	2	...	1	...	...	117
1932	129	...	...	...	...	...	...	1	2	...	7	...	6	...	1	...	5	22
1933	530½	...	35	...	...	34	...	96	...	...	18	2	1	...	145	...	4	335
1934	182	3	...	...	...	...	...	5	...	1	...	13	...	...	5	6	6	39
1935							No Records											
1936							No Records											
1937							No Records											
1938							No Records											
1939	339½	...	...	...	...	25	...	2	28	...	...	...	...	1	8	27	4	95
1940	699½	1	...	...	...	42	12	38	110	13	1	...	12	...	3	1	1	234
1941	257	7	1	...	2	40	...	59	44	2	...	...	4	...	...	...	16	175
1942	361½	3	...	7	3	57	1	6	48	...	...	...	...	...	7	46	...	178
1943	298½	...	...	...	...	13	...	...	83	...	...	1	...	2	1	2	13	115
1944	558 3/4	...	...	...	...	78	...	17	227	17	...	...	...	...	...	46	1	386
1945	269¼	21	...	...	...	4	...	...	148	2	...	...	...	...	...	204	23	402
1946	236	...	...	...	...	...	...	...	89	...	...	...	...	...	...	9	13	111
1947	34	...	...	...	...	...	...	55	...	32	...	...	...	...	...	...	...	87
Totals	4,308½	35	36	17	9	327	13	636	781	70	26	16	26	3	171	341	86	2,593

*Includes 11 channel cat, 74 sauger, and 4 lawyer.

above the mouth of the Huron River. Fifty-one collections were taken over that stretch, and 11 additional collections were taken from tributaries and from adjoining Lake Erie.

The following annotated list of fishes from the Detroit River includes notes on general abundance for each species. These notes on abundance are mostly from the seining collections of 1935.

Annotated List of Fishes

(Note - An asterisk preceding a species' name indicates the record for that species was obtained in some year other than 1935.

Petromyzonidae

Ichthyomyzon unicuspis Hubbs and Trautman, silver lamprey: rare.

Acipenseridae

*Acipenser fulvescens Rafinesque, rock sturgeon: once taken in large numbers by commercial fishermen but now probably rare.

Lepisosteidae

Lepisosteus osseus oxyurus Rafinesque, northern longnose gar: common.

Hiodontidae

*Hiodon tergisus Le Sueur, mooneye: collected in the early 1900's.

Clupeidae

Dorosoma cepedianum (Le Sueur), gizzard shad: a considerable number collected at one station in 1935. A considerable mortality of young shad occurred in the Detroit River in December, 1947.

Coregonidae

*Coregonus clupeaformis (Mitchell), whitefish: formerly abundant but now probably few or rare if present at all.

*Leucichthys artedi (Le Sueur), cisco: formerly abundant but now probably few or rare if present at all.

Catostomidae

Catostomus commersonnii commersonnii (Lacépède), common white sucker: abundant.

Hypentelium nigricans (Le Sueur), hog sucker: rare

*Erimyzon oblongus (Mitchell), creek chubsucker: recorded in early 1900's.

Moxostoma aureolum (Le Sueur), northern redhorse: rare

*Placopharynx carinatus Cope, river redhorse: recorded in the late 1800's.

Cyprinidae

Cyprinus carpio Linnaeus, carp: abundant.

Carassius auratus (Linnaeus), goldfish: abundant.

Nocomis biguttatus (Kirtland), hornyhead chub: few.

Nocomis micropogon (Cope), river chub: rare

Hybopsis storerianus (Kirtland), silver chub: few.

Notemigonus crysoleucas auratus (Rafinesque), western golden shiner: common.

Notropis atherinoides, emerald shiner: common.

Notropis cornutus chrysocephalus (Rafinesque), central common shiner: common.

Notropis hudsonius hudsonius (Clinton), northern spottail shiner: abundant.

Notropis heterodon (Cope), blackchin shiner: few.

Notropis spilopterus (Cope), spotfin shiner: common.

Notropis deliciosus stramineus (Cope), northeastern sand shiner: few.

Notropis volucellus volucellus (Cope), northern mimic shiner: common.

Notropis heterolepis heterolepis Eigenmann and Eigenmann, northern blacknose shiner: common.

*Hybognathus nuchalis Agassiz, western silvery minnow: reported once in the mid-1800's.

*Pimephales promelas promelas Rafinesque, northern fathead minnow: reported in the mid-1800's.

Hyborhynchus notatus (Rafinesque), bluntnose minnow: common.

*Campostoma anomalum , stoneroller: recorded in the late 1800's.

Ameiuridae

*Ictalurus lacustris lacustris (Walbaum), northern channel catfish: reported in the general creel census of 1932 and 1934.

Ameiurus melas melas (Rafinesque), northern black bullhead: common.

Ameiurus nebulosus nebulosus (Le Sueur), northern brown bullhead: common.

Ameiurus natalis natalis (Le Sueur), northern yellow bullhead: few.

Schilbeodes mollis (Hermann), tadpole madtom: rare.

Umbridae

Umbra limi (Kirtland), western mudminnow: few.

Esocidae

*Esox vermiculatus Le Sueur, mud pickerel: reported in the mid-1800's.

Esox lucius Linnaeus, northern pike: common.

*Esox masquinongy masquinongy Mitchell, Great Lakes muskellunge: specimens reported caught from the Detroit River were entered in the Detroit Free Press fishing contest in 1933 and 1934.

Anguillidae

*Anguilla bostoniensis (Le Sueur), American eel: there was a plant of 6,000 eels in the Detroit River in 1883.

Cyprinodontidae

Fundulus diaphanus menona Jordan and Copeland, western banded killifish: abundant.

*Fundulus notatus (Rafinesque), blackstripe topminnow: reported in the mid-1800's.

Gadidae

*Lota lota maculosa (Le Sueur), American burbot: reported in 1904 as occurring quite abundantly; four specimens were reported from the 1933 creel census on the Detroit River.

Percopsidae

*Percopsis omiscomaycus (Walbaum), troutperch: collected in 1937 from a canal at the upper end of the Detroit River.

Serranidae

Lepibema chrysops (Rafinesque), white bass: common.

Percidae

Perca flavescens (Mitchell), yellow perch: abundant.

Stizostedion vitreum vitreum (Mitchell), yellow pikeperch: common.

Hadropterus maculatus (Girard), blackside darter: few.

Percina caprodes semifasciata (DeKay), northern logperch: common.

Cottogaster copelandi (Jordan), channel darter: present.

Boleosoma nigrum eulepis Hubbs and Green, scaly Johnny darter: present.

*Ammocrypta pellucida (Baird), northern sand darter: noted in early records.

*Poecilichthys caeruleus caeruleus (Storer), northern rainbow darter: noted in early records.

*Poecilichthys flabellaris flabellaris (Rafinesque), barred fantail, present.

Microperca microperca microperca (Jordan and Gilbert), northern least darter: few.

*Etheostoma blennioides blennioides Rafinesque, northern greenside darter: noted in early records.

Centrarchidae

Micropterus dolomieu dolomieu Lacépède, northern smallmouth bass: common.

Micropterus salmoides Lacépède, largemouth bass: common.

Lepomis gibbosus (Linnaeus), pumpkinseed: common.

Lepomis macrochirus macrochirus Rafinesque, common bluegill: few.

Lepomis megalotis peltastes Cope, Great Lakes longear sunfish: few.

Ambloplites rupestris rupestris (Rafinesque), northern rock bass: common.

Pomoxis annularis Rafinesque, white crappie: few.

Atherinidae

Labidesthes sicculus sicculus (Cope), northern brook silverside: abundant.

Sciaenidae

*Aplodinotus grunniens Rafinesque, freshwater sheepshead: creel census returns indicate that this species is quite common in the Detroit River.

Cottidae

*Cottus bairdii kumlieni (Hoy), Great Lakes muddler: collected in 1937.

Gasterosteidae

Eucalia inconstans (Kirtland), brook stickleback: few.

TOLERANCE LIMITS OF FISH TO POLLUTANTS

Water standards for fish are different from those which will define water as drinkable for humans or satisfactory for industrial use. Water usable for many industries may not support fish life, or fish may thrive in water which is unsafe for human consumption due to the presence of certain harmful bacteria, or fish may die due to the presence of chlorine in water safe for human consumption.

To define water as suitable or unsuitable for aquatic life is complicated because various species of aquatic organisms and individuals of the same species have different degrees of tolerance to many stream pollutants. The presence or survival for a short time of fish in waters suspected of pollution does not constitute absolute evidence that these waters are satisfactory or safe for fish. (Ellis, 1937).

The problem of defining stream pollution is too complex to allow the use of a single index. Ellis (1944) states that a large series of field studies has shown that natural water conditions can be ascertained satisfactorily for pollution studies as regards fisheries problems by repeated determinations at different times of night and day and at various seasons of the year of the (1) dissolved oxygen, (2) pH, (3) ionizable salts, (4) total ammonia, and (5) suspensoids. The determinations of these factors not only give specific data concerning particular conditions but also concerning several complexes which vary even in unpolluted streams and which are definitely affected by many forms of pollutions.

(1) Dissolved oxygen: After making 5,809 determinations of dissolved oxygen in waters from various streams of the United States during the midsummer months, Ellis (1937) states "These data collected from localities where fish had had opportunity to choose for themselves point very strongly to 5 p.p.m. as the lower limit of dissolved oxygen, if the complex is to

maintain a desirable fish fauna under natural river conditions."

(2) pH limits: Quoting Ellis (1944) "The pH (hydrogen-ion concentration) of inland streams, excepting badly polluted portions, as seen in a review of 10,000 readings made during the past four years lies in general between the values of pH 7.4 and pH 8.5 with the extreme range (in our data) of pH 6.6 and pH 9.0 in streams from which no specific factor causing the deviation of hydrogen-ion concentration was readily observable."

Experimental tests have demonstrated that many species of fresh-water fishes are able to withstand a wide range in pH. Wiebe (1931) reports that goldfish survive rapid changes from pH 7.2 to pH 9.6; largemouth black bass, from pH 6.1 to pH 9.5; smallmouth black bass, from pH 6.6 to pH 9.3; and sunfish from pH 7.2 to pH 9.6.

(3) Ionizable salts: According to Ellis (1937) determinations of specific conductance of inland fresh waters show that those portions of inland streams and rivers which were supporting good, mixed fish faunae in general lay between 150 and 500 mho x 10^{-6} at 25°C. From the above field studies it was found advisable to look for specific pollutant action if the conductivity of the water exceeded 1,000 mho in all streams except those draining the more alkaline regions.

(4) Ammonia: Ammonium compounds present both a hazard due to high toxicity of ammonium carbonate for most aquatic animals and an important source of nitrogen for the lower plants in the aquatic food chain.

Many investigators have tested the toxic effects of ammonium compounds and have shown that aquatic organisms are particularly sensitive to ammonium carbonate, the form in which ammonia is most frequently found in inland waters. Ellis and Chipman (1936) repeated many of the earlier tests and found that pH is a large factor in regulating the toxicity of ammonium compounds for aquatic animals, ammonium salts becoming more toxic in more alkaline media. Quoting Ellis (1937) ". . . the existing literature and the data from our experiments indicate that under average stream conditions with pH value 7.4 and pH 8.5, 2.5 p.p.m. of ammonia will be harmful to many individuals at least of the common aquatic species. Therefore, in view of the small amount of ammonia found in unpolluted natural flowing waters, 1.5 p.p.m. dissolved ammonia was considered the maximal amount of dissolved ammonia not suggestive of specific organic pollution."

(5) Suspensoids: Matter in suspension in fresh water consists normally of erosion silt, organic detritus, plankton, and bacteria. This mixture, with the exception of plankton, may be greatly augmented by man's agencies as quantities of powdered rock, cellulose pulps, sawdust, semi-solid sewage, and other debris are added.

A large series of experiments by Ellis (1944) have demonstrated that rock powders, blast-furnace slags, cinder particles, and even coal washings will cut and injure fish gills if the particles be larger than those which will pass through a 1,000-mesh (to the inch) screen. In these tests it was shown that the larger the particles, and the greater their hardness and angularity, the greater the possibility of injury to gill structures. Ellis (1944) recommends that all particulate matter introduced by man of a hardness of "one" or greater should be so finely pulverized that it would pass through a 1,000-mesh screen, and should be so dilute that the resultant turbidity would not reduce the millionth intensity level (the level at which the light entering the surface of the stream would be reduced to one-millionth of its surface intensity) to less than 5 meters. The quantity should be controlled so that the stream could carry the powder away without blanketing the bottom to a depth of more than one quarter of an inch.

The following summary of the lethal limits of individual substances, together with bibliographic references and statements concerning the test animals used and conditions of the experiments, were extracted from "Detection and measurement of stream pollution" by M. M. Ellis (1937):

PHENOL and CRESOL

Phenol

An important constituent of gas wastes, many chemical effluents, and even some sewage products. Phenol may also come into streams from sheep dips, and other establishments where livestock are disinfected. Shelford (1917), 70-75 p.p.m. in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour: Powers (1917), 51 p.p.m. in distilled water killed goldfish in 1 hour 30 minutes to 2 hours 20 minutes; Demyanenko (1931), 16.6-20 p.p.m. lethal to fishes, some can live in 15 p.p.m., but their flesh acquired phenolic smell; Alexander, Southgate, and Bassindale (1935), 0.4-0.6 p.p.m. caused trout to overturn in 8 hours 20 minutes; Adams (1927), 10 p.p.m. in Nile River water killed cladocerans, Daphina sp., and copepods, Cyclops sp.; M.M.E., 10 p.p.m. in hard water killed goldfish Carassius auratus, in 72 hours or less; 1 p.p.m. apparently not injurious to goldfish in exposures of 100 hours; 8 p.p.m. in soft water killed cladocerans, Daphnia magna.

Cresol

A mixture of the various isomeric compounds of this group. The mixture and the individual compounds occur in gas wastes in varying proportions and the mixture is used in various sheep dips and other preparations for the disinfecting of livestock. Both gas wastes and dipping vats have on occasion been the sources of stream pollution by this substance. This mixture and two of the component isomers are discussed below.

Cresol

Adam (1917), 10 p.p.m. in Nile River water killed cladocerans, Daphnia sp.; copepods, Cyclops sp.; Demyanenko (1931), 17-20 p.p.m. lethal for fishes.

Orthocresol

Shelford (1917), 55-65 p.p.m. in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour; M. M. E., 10-20 p.p.m. in hard water killed goldfish, Carassius auratus, in 3-5 days.

Paracresol

Shelford (1917), 80-90 p.p.m. in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour; Southgate, Pentelow, and Bassindale (1933), 6.2 p.p.m. in tap water caused trout, Salmo irideus, to float helpless on their backs in 1 hour 40 minutes, if the water carried circa 10 p.p.m. of dissolved oxygen and in 13 minutes if the water carried only 3 p.p.m. dissolved oxygen.

Cresylic acid

Mine floatation wastes; sheep and cattle dips. M. M. E., 0.1 p.p.m. in hard water killed goldfish, Carassius auratus, in 5 days, and 1 p.p.m. in 6-48 hours; 0.1 p.p.m. in soft water killed cladocerans, Daphnia magna, in 72 hours.

AMMONIUM COMPOUNDS

Ammonium carbonate

Gas wastes; wool-washings; tanner effluents. Clark and Adams (1913), 155-197 p.p.m. fatal to shiners and carp in a few minutes to a few hours; Shelford (1917), 600-800 p.p.m. killed orange-spotted sunfish, Lepomis humilis in 1 hour; M. M. E., 100 p.p.m. in hard water killed goldfish in 4-10 hours, 48 p.p.m. in 6 days, 10 p.p.m. tolerated for more than 100 hours without apparent effect.

Ammonium chloride

Gas wastes; various chemical wastes. Clark and Adams (1913), 180 p.p.m. in tap water, no effect on shiners or carp; Wells (1915b), 535 p.p.m. in tap water killed bluegills, Lepomis pallidus in 4 hours 45 minutes, and same amount in distilled water killed bluegills in 18 days; Shelford (1917), 700-800 p.p.m. killed orange-spotted sunfish, Lepomis humilis, in 1 hour; Powers (1917), 1,712 p.p.m. in distilled water killed goldfish, Carassius auratus, in 6-18 hours; M. M. E., 268 p.p.m. in hard water, killed goldfish in 6 days; 535 p.p.m. killed cladocerans, Daphnia magna, in 6 hours.

Ammonium ferrocyanide

Gas wastes. Shelford (1917), 150-200 p.p.m. killed orange-spotted sunfish, Lepomis humilis, in 1 hour.

Ammonium hydroxide

Wool washings; chemical wastes; gas wastes. Since ammonia gas NH_3 unites readily on mixing with water forming the hydroxide, these two compounds are considered together here. Clark and Adams (1913), 9.4 p.p.m. (ammonium hydroxide) did not kill shiners, carp, and large suckers but 13 p.p.m. killed all these fish, 20 p.p.m. being fatal in 15 minutes; Belding (1928), 6.25 p.p.m. killed brook trout in 24 hours; Weigelt, Saare, and Schwab (1885), 250 p.p.m. (ammonia) killed trout in 2 hours; Shelford (1917), 7-8 p.p.m. (ammonia) in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour; M. M. E., 2-2.5 p.p.m. (ammonia) in hard water fatal to goldfish, Carassius auratus, and yellow perch, Perca flavescens, in 24 hours to 4 days.

Ammonium nitrate

Chemical industries; manufacture of explosives; in fertilizers. Wells (1915b), 800 p.p.m. in tap water killed bluegills, Lepomis pallidus, in 3.9 hours; in distilled water lethal to bluegills in 16 days; Powers (1917), 4,545 p.p.m. in distilled water killed goldfish, Carassius auratus, in 90 hours.

Ammonium sulphate

Chemical wastes; gas wastes; fertilizers. Wells (1915b), 66 p.p.m. in tap water killed bluegills, Lepomis pallidus, in 3 hours 30 minutes, in distilled water lethal to bluegills in 17 days; Shelford (1917), 420-500 p.p.m. in tap water killed Lepomis humilis, in 1 hour; M. M. E., 264 p.p.m. in hard water killed goldfish, Carassius auratus, in 6 days or less.

Ammonium sulphide

Chemical wastes; in wastes from some beet-sugar processes; in some gas wastes. M. M. E., 100 p.p.m. in hard water killed goldfish, Carassius auratus, in 72 hours, 10 p.p.m. in hard water, goldfish survived more than 100 hours of exposure.

Ammonimu thicoyanate

Gas wastes; chemical industries. Shelford (1917), 289-300 p.p.m. in tap water killed orange-spotted sunfish in 1 hour; Demyanenko (1931), 200 p.p.m. lethal for fish.

OILS AND ETHER-EXTRACTABLE MATERIALS

Naphthenic acids

These compounds are listed among the solutes which may occur in refinery wastes (American Petroleum Institute, 1935), and Kupzis (1902) believes the naphthenic compounds to be among the most toxic substances to fish, passing from crude oil into water. Kupzis (l.c.) using fractions containing the naphthenic acids extracted from various crude oils, gives the following lethality findings for the naphthenic acid fraction (which of course must not be considered as representing a single pure compound in this case). In tap water (hard) 3 p.p.m. killed percoid fishes, Acerina cernua, in 6-12 hours; 5 p.p.m. killed pickerel, Esox lucius, 36-48 hours; the minnow, Abramis brama, 72 hours; the red-eyed minnow, Scardinius erythrophthalmus, 26 hours; and the perch, Perca fluviatilis, in 16-23 hours; 20 p.p.m. killed carp, Cyprinus carpio, in 26-36 hours, and goldfish, Carassius auratus, in 8-16 hours. Several other European species tested are not listed here.

Naphthalene

Aniline and coal-tar industries. Demyanenko (1931), 10 p.p.m. lethal to fish.

THIOSULFATES AND SULFIDES

Ammonium sulphide

Chemical wastes; in wastes from some beet-sugar processes; in some gas wastes. M. M. E., 100 p.p.m. in hard water killed goldfish, Carassius auratus, in 72 hours, 10 p.p.m. in hard water, goldfish survived more than 100 hours of exposure.

Carbon bisulphide

Gas wastes; as a solvent in various chemical industries. Weigelt, Saare, and Schwab (1885), a 7 minute exposure to 5,000 p.p.m. killed trout 2 days later; Shelford (1917), 100-127 p.p.m. in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour.

Hydrogen sulphide

Produced by decomposition of many types of organic effluents, both municipal and industrial, and occurs in many trade wastes, chemical wastes, and gas wastes. This gas which readily dissolves in water is not only harmful in itself but in its decomposition may produce colloidal sulphur, which is also a pollution hazard. Weigelt, Saare, and Schwab (1885), a 3-hour exposure to 100 p.p.m. in tap water was fatal to tench, Tinca vulgaris, 8 days later, and 10 p.p.m. in tap water caused trout to float on back in 15 minutes; Shelford (1917), 4.9-5.3 p.p.m. in tap water killed orange-spotted sunfish, Lepomis humilis, in 1 hour; Belding (1929), 0.086 p.p.m. lethal for brook trout, Salvelinus fontinalis, 3.8 p.p.m. for the sucker, Catostomus commersonnii, 4.3 p.p.m. for aquarium goldfish, Carassius auratus, and 6.3 p.p.m. for carp, Cyprinus carpio; M. M. E., 10 p.p.m. in hard water killed goldfish, Carassius auratus, in 96 hours or less, 5 p.p.m. killed some goldfish in 200 hours, and 1 p.p.m. in soft water killed cladocerans, Daphnia magna, in 72 hours or less.

Sodium sulphide

In some beet-sugar factory effluents and in some paper-pulp wastes. Weigelt, Saare, and Schwab (1885), a 1-hour exposure to 1,150 p.p.m. in tap water kill tench, Tinca vulgaris, 6 days later.

CYANIDES

Potassium cyanide

Ore milling operations; chemical works; electroplating; and in effluents from coke ovens. (See Tupholme, 1933) Powers (1917), 0.78 p.p.m. in distilled water killed goldfish in 43-118 hours; Calatroni (1928), 15 p.p.m. in tap water immobilized tadpoles with fatal results; McArthur and Baillie (1929), 65 p.p.m. killed cladocerns, Daphnia magna; Southgate, Pentelow, and Bassindale (1933), 0.27 p.p.m. KCN (equal to 0.11 p.p.m. CN) at temperature of 7^{o} - 9^{o} C. caused trout to float helpless on back on about 2 hours if the dissolved oxygen in the water were circa, 11 p.p.m., but in 10 minutes if the water carried only 3 p.p.m. dissolved oxygen; Alexander, Southgate, and Bassindale (1935) find 0.5 p.p.m. KCN (0.2 p.p.m. CN) will cause trout to overturn and become helpless in 15 minutes; M. M. E., 1 p.p.m. in river water caused glochidia of fresh-water mussels to close, rendering them incapable of attachment on fishes, and 0.1-0.3 p.p.m., in hard water killed goldfish in 3-4 days.

Potassium ferricyanide

Penny and Adams (1863), 2,000 p.p.m. not lethal to minnows and goldfish.

Potassium ferrocyanide

Penny and Adams (1863), 2,000 p.p.m. not lethal to minnows, and goldfish, Weigelt, Saare, and Schwab (1885), trout survived 1 hour exposure to 8,723 p.p.m. in tap water without symptoms.

CHLORIDES

Ammonium chloride

See ammonium compounds.

Barium chloride

Some chemical wastes; some alkaline pools. Powers (1917), 5,000 p.p.m. in distilled water killed goldfish, Carassius auratus, in 12-17 hours.

Cadmium chloride

Pigment works; calico printing; chemical wastes. Powers (1917), 0.0165 p.p.m. in distilled water killed goldfish in 8 hours 40 minutes to 18 hours.

Calcium chloride

Wastes from bromine and salt works; in waters from oil wells; antidust road surfacing. Wells (1915b), 555 p.p.m. in tap water caused pathological degeneration of tail fin of rock-bass, Ambloplites rupestris, in an exposure of 1 week; Garrey (1916), 2,775 p.p.m. in distilled water killed strawcolored minnows, Notropis blennius, in 2-4 days, but this species did not succumb to 277 p.p.m. in distilled water in 5-7 weeks; Powers (1917), 7,752 p.p.m. in distilled water killed goldfish, Carassius auratus, in 22-27 hours; Wiebe, Burr, and Faubion (1934), 5,000 p.p.m. killed golden shiners, Notemigonus. crysoleucas, in 143 hours.

Cobaltous chloride

Pigment works; chemical industries. M. M. E., 1,000 p.p.m. in hard water killed goldfish, Carassius auratus, in 30-32 hours; 10 p.p.m. in soft water fatal to some goldfish in 168 hours; others survived exposure to this amount for longer periods.

Cupric chloride

Powers (1917), 0.0188 p.p.m. in distilled water killed goldfish in 3 hours 30 minutes to 7 hours; Carpenter (1927), 672 p.p.m. in distilled water killed the minnow, Leuciscus phoxinus, in 82 minutes.

Ferric chloride

Dye industries; some ore milling operations; various chemical wastes. Powers (1917), 9 p.p.m. in distilled water killed goldfish, in 20 hours; Carpenter (1927), 270 p.p.m. in distilled water killed minnows, Leuciscus phoxinus, in 90 minutes; M. M. E., 100 p.p.m. in very soft water killed goldfish, Carassius auratus, in 1 hour to 1 hour 30 minutes, but same quantity of ferric chloride in hard water was not detrimental to goldfish in a 96 hour exposure.

Lithium chloride

Found in some mineral springs. Powers (1917), 3,750 p.p.m. in distilled water killed goldfish in 22-26 hours.

Magnesium chloride

A component of various waste waters from oil wells, and some industrial wastes. Garrey (1916), 476 p.p.m. in distilled water killed straw-colored minnow, Notropis blennius, in 4-6 days; Powers (1917), 6,757 p.p.m. in distilled water killed goldfish in from 78 hours to 21 days; Wiebe, Burr, and Faubion (1934), 5,000 p.p.m. in distilled water killed golden shiner, Notemigonus crysoleucas, in 96 hours.

Mercuric chloride

Wiegelt, Saare, and Schwab (1885), 500 p.p.m. in tap water killed large trout in 54 minutes; Carpenter (1927), 13.6 p.p.m. in distilled water killed minnow, Leuciscus phoxinus, in 42 minutes.

Potassium chloride

Garrey (1916), 373 p.p.m. in distilled water killed straw-colored minnows, Notropis blennius, in 12-29 hours; Powers (1917), 74.6 p.p.m. in distilled water lethal for goldfish in 4 hours 4 minutes to 15 hours.

Sodium chloride

Brine works; waste waters from oil wells; effluents from some dairy industries. Garrey (1916), 2,500 p.p.m. in distilled water killed straw-colored minnow, Notropis blennius, in 9-24 days (solution, $\Delta = 0.105$); Powers (1917), 11,765 p.p.m. in distilled water killed goldfish in 17 hours; Wiebe, Burr, and Faubion (1934), 5,000 p.p.m. in distilled water killed golden shiners, Notemigonus crysoleucas, in 148 hours and largemouth black bass in 200-250 hours; M. M. E., 1 p.p.m. in distilled water killed cladoceran, Daphnia magna, in 3 hours, 5,000 p.p.m. in Mississippi River water apparently not harmful to goldfish in 25-day exposure, but in 10,000 p.p.m. in Mississippi River water killed goldfish in 4-10 days.

Stannous chloride

M. M. E. 1,000 p.p.m. in hard water killed goldfish in 4-5 hours.

Strontium chloride

Powers (1917), 15,384 p.p.m. in distilled water killed goldfish in 17-31 hours.

ALKALINITY OR ACIDITY

Ammonium hydroxide

See ammonium compounds.

Calcium hydroxide

Tannery-wastes; leather works. Weigelt, Saare, and Schwab (1885), 700 p.p.m. in tap water killed trout in 26 minutes; Marsh (1907), 18 p.p.m. (as calcium oxide) fatal to trout fry.

Potassium hydroxide

Soap works; from some types of ashes. Wells (1915), 56 p.p.m. in distilled water killed bluegills, *Lepomis pallidus*, in 4 hours 25 minutes, 28 p.p.m. apparently not harmful to bluegills in 10-day exposures.

Sodium hydroxide

Soap factories; wood ashes. Clark and Adams (1913), 96 p.p.m. in tap water killed shiners, carp, and suckers in 2-10 minutes; Standing Committee on River Pollution (1924), 50 p.p.m. in distilled water was not fatal to perch and roach in a 2-hour exposure.

Ammonium carbonate

See ammonium compounds.

Potassium bicarbonate

Penny and Adams (1863), 2,000 p.p.m. killed minnows and goldfish.

Sodium carbonate

Found in many chemical effluents. Clark and Adams (1913), 250-300 p.p.m. killed shiners, carp and large suckers in tap water in a few hours; Wells (1915b), 530 p.p.m. in tap water killed bluegills, *Lepomis pallidus*, in 3 days.

Aluminium ammonium sulphate

Dye works and cloth printing industries. Weigelt, Saare, and Schwab (1885), 523 p.p.m. in tap water caused large trout to float on side after

10 hours' exposure.

Aluminium potassium sulphate

Dye works; tanneries; leather works. Penny and Adams (1863), 250 p.p.m. killed goldfish and minnows; Weigelt, Saare, and Schwab (1885), 544 p.p.m. in tap water killed California salmon in 6 hours, and medium trout in 15 hours; M. M. E., 1,000 p.p.m. in hard water killed goldfish, Carassius auratus in 1-10 hours, 100 p.p.m. killed goldfish in 12-96 hours, although some survived this strength over 100 hours.

Ammonium sulphate

See ammonium compounds.

Cadmium sulphate

Same sources as cadmium chloride. Carpenter (1927), 1,042 p.p.m. in distilled water killed minnows, Leuciscus phoxinus, in 3 hours.

Cupric sulphate

Because of the wide use of this compound in both industry and in aquatic investigations, and because of the variation in limits of lethality copper sulphate as given by many writers, owing to differences in water, in carbonate content, and in associated substances, a larger number of references have been included for copper sulphate than for most compounds in this list. Penny and Adams (1863), 10 p.p.m. fatal to goldfish and minnows, but 5 p.p.m. under the conditions of their tests were not lethal to these fishes; Moore and Kellerman (1905), 0.143 p.p.m. in hatchery water (Cold Spring Harbor, N. Y.), maximum strength tolerated by brook trout, and 0.33 p.p.m. maximum for carp and suckers, 0.4 p.p.m. for catfish, 0.5 p.p.m. for goldfish, 1.33 p.p.m. for sunfish, 2.0 p.p.m. for black bass; Carpenter (1927), 399 p.p.m. in distilled water killed minnows, Leuciscus phoxinus, in 62 minutes; Catt (1934), 0.5 p.p.m. in lake water not lethal to white perch and yellow perch in 15 hours, but 1 p.p.m. in lake water killed white and yellow perch in 1 to 10 hours; M. M. E., 2 p.p.m. in hard water killed goldfish, Carassius auratus, in 24-96 hours; catfish, *Ameiurus nebulosus*, in 96-200 hours; 1 p.p.m., some goldfish in 72 hours; 1.25 p.p.m., the amphipods, *Gammarus fasciatus* and *Eucrangonyx gracilis*, in 17-20 hours; 10 p.p.m., the isopod, *Mancasellus macrourus*, in 16-48 hours; 1 p.p.m. in distilled water killed cladocerans, *Daphnia magna*, in 15 minutes to 2 hours, and 0.25 p.p.m. in distilled water in 30 minutes to 3 hours.

Ferric potassium sulphate

Dye mordant; calico printing. Weigelt, Saare, and Schwab (1885), 1 minute exposure to 10,000 p.p.m. not fatal to tench.

Ferric sulphate

Chemical industries; as a coagulant for sewage precipitation. Clark and Adams (1913), 0.716 p.p.m. in distilled water killed shiners, carp, and suckers in 12-24 hours.

Ferrous sulphate

Waters from mines containing pyrites; in pickle liquor from industrial plants cleaning iron plate or wire. Weigelt, Saare, and Schwab (1885), 2,721 p.p.m. in tap water killed trout and California salmon in 31-66 minutes; Clark and Adams (1913), 2.9 p.p.m. in distilled water killed shiners, carp, and suckers in 4-24 hours; Carpenter (1927), 315 p.p.m. in distilled water killed minnows, *Leuciscus phoxinus*, in about 3 hours; M. M. E., 1,000 p.p.m. in hard water killed goldfish, *Carassius auratus*, in 2-10 hours, 100 p.p.m. in hard water apparently not harmful to goldfish in a 96-hour exposure.

Lead sulphate

Carpenter (1925), 25 p.p.m. in distilled water killed goldfish, *Carassius auratus*, in 4 days and minnows, *Leuciscus phoxinus*, in 2-3 hours.

Potassium sulphate

Wells (1915b), 869 p.p.m. in tap water killed bluegills, *Lepomis pallidus*, in 4 days.

Sodium sulphate

Harukawa (1922), 500 p.p.m. in tap water not injurious to goldfish in

24 hours.

Zinc sulphate

Wastes from electrolytic refineries of zinc, incrustations developing from exposed zinc sulphide ores; mine tailings; several chemical effluents. Carpenter (1927), 404 p.p.m. in distilled water killed minnows, *Leuciscus phoxinus*, in 3 hours 20 minutes; M. M. E., 1,000 p.p.m. in hard water killed goldfish in 1-4 hours, 100 p.p.m. fatal to many goldfish in 5 days.

Ammonium nitrate

See ammonium compounds.

Calcium nitrate

Some chemical wastes. Powers (1917), 6,061 p.p.m. in distilled water killed goldfish, in 43-48 hours.

Cupric nitrate

Dilling and Healey (1926), 0.0188 p.p.m. in tap water killed many tadpoles and interfered with development of those which survived.

Lead nitrate

Rushton (1922), 10 p.p.m. in stream water killed trout in 2 hours 15 minutes; Carpenter (1925), 250 p.p.m. in distilled water killed goldfish in 4-5 days and minnows, *Leuciscus phoxinus*, in 2-3 hours; Dilling and Healey (1926), 1.6 p.p.m. retards growth of tadpoles and 3.3 p.p.m. lethal for tadpoles in tap water; Carpenter (1930), 165 p.p.m. in distilled water, if given sufficient exposure will kill steel-colored minnow, *Notropis whipplii*; common shiner, *Notropis cornutus*; blunt-nosed minnow, *Hyborhynchus notatus*; silver-mouthed minnow, *Ericymba buccata*; sucker-mouthed minnow, *Phenacobius mirabilis*; creek chub, *Semotilus atromaculatus*; stoneroller, *Campostoma anomalum*; common sucker, *Catostomus commersonnii*; chub sucker, *Eriomyzon sucetta*; Johnny darter, *Boleosoma nigrum*; fan-tailed darter, *Etheostoma flabellare*; log perch, *Percina caprodes*; and bluegills, *Lepomis pallidus*; M. M. E., 100 p.p.m. in hard water fatal to goldfish, *Carassius auratus*, in

80 hours; 10 p.p.m. in hard water, without apparent injury to goldfish, in 96 hours' exposure.

<u>Magnesium nitrate</u>

Powers (1917), 12,500 p.p.m. killed goldfish in 14-16 hours.

<u>Sodium nitrate</u>

Fertilizers. Powers (1917), 1,282 p.p.m. in distilled water killed goldfish in 14 hours; M. M. E., 4,000 p.p.m. in hard water killed goldfish in 80 hours but 3,000 p.p.m. apparently did not injure goldfish in 100-hour exposures.

<u>Strontium nitrate</u>

Powers (1917), 9,615 p.p.m. in distilled water killed goldfish in 32-146 hours.

<u>Sodium fluoride</u>

In certain brewery and distillery wastes; also found in some soils. M. M. E., 1,000 p.p.m. in hard water killed goldfish in 60-102 hours.

<u>Hydrochloric acid</u>

In effluents from many chemical processes. Weigelt, Saare, and Schwab (1885), 1,000 p.p.m. in tap water caused trout to overturn helpless in 2-5 minutes; Wells (1915a), 3.6 p.p.m. in distilled water killed green sunfish, <u>Lepomis cyanellus</u>, in 48 hours. Standing Committee on Rivers Pollution (1924), 200 p.p.m. in distilled water produced general collapse in perch and roach; M. M. E., 166 p.p.m. in hard water killed goldfish, <u>Carassius auratus</u>, in 4-7 hours; 157 p.p.m. in hard water apparently did not injure goldfish in over 100 hours' exposure; 56 p.p.m. in soft water killed cladocerans, <u>Daphnia magna</u>, in 17-72 hours.

<u>Nitric acid</u>

Occurs in many wastes from chemical industries. It is easily broken into water and oxides of nitrogen. Weigelt, Saare, and Schwab (1885), trout after 34 minutes in 1,000 p.p.m. in tap water were helpless; Carpenter (1927), sufficient quantities to bring the water to pH 4.4 killed the minnow, *Leuciscus phoxinus*, in 7 hours, while quantity sufficient to bring the water to pH 5.2 was without apparent effect on this species of fish; M. M. E., 750 p.p.m. in hard water killed goldfish, *Carassius auratus*, in 30 minutes to 1 hour, and 200 p.p.m. in hard water were without apparent effect on goldfish in exposures of over 100 hours.

Sulphuric acid

Pickle liquor from sheet metal and wire factories; waters from coal and iron mines; various chemical wastes. Wells (1915), 7.36 p.p.m., in distilled water killed bluegills, *Lepomis pallidus*, in 60 hours, but 3.68 p.p.m. apparently harmless over period of 1 month. M. M. E., 59 p.p.m. in very soft water killed goldfish, *Carassius auratus*, in 1 hour to 1 hour 15 minutes, 138 p.p.m. in hard water in 4 hours, 100 p.p.m. in hard water apparently not injurious to goldfish in 100-hour exposures; 29 p.p.m. in soft water killed cladocerans, *Daphnia magna*, in 24-72 hours.

Chromic acid

Chrome tannery wastes. M. M. E., 100 p.p.m. in hard water did not kill goldfish, *Carassius auratus*, in 100 hours' exposure; the same amount in very soft water killed goldfish in 30-35 minutes.

Oxalic acid

Bleaching, dying, and various chemical industries. M. M. E., 1,000 p.p.m. in hard water killed goldfish, *Carassius auratus*, in 25-30 minutes; 200 p.p.m. in hard water produced no apparent injury during exposures of 100 hours. This acid is readily precipitated out of waters by calcium salts.

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