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WAYS AND MEANS OF MEASURING THE DANGERS OF POLLUTION TO FISHERIES

BY

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ERRATA

Page 97, line 17, for first *larval* read *pupal.*
Page 112, in legend, for *jonessi* read *jonesii.*
Page 114, in legend, for *or* read *of.*
Page 125, line 4, for *Bonosa* read *Bonasa.*
Page 131, in legend, for *hirundinaceus* read *hirudinaceus.*
Page 138, last line, for *coccoon* read *cocoon.*
Plate XII, explanation page, next to last line, for *acrivora* read *aerivora.*
Plate XIII, explanation page, next to last line, for *White-grubs* read *White-grub.*
Page 293, Figure 5*a* was reversed in printing, and the two items of the legend should change places.
Page 515, second table, for *Pelocoris femorata* read *Pelocoris femoratus.*

Article II.—*Ways and Means of measuring the Dangers of Pollution to Fisheries.* By Victor E. Shelford.

Introduction

We are at war with a powerful and well-organized nation which has planned and saved with war in view. In our belated endeavor to conserve existing resources and to develop new and latent ones new problems are constantly arising. Some of these concern fisheries and the pollution of waters. The U. S. Fish Commission is urging the public to eat fish—to make every day a fish day. This was no doubt done in the early days of our republic, for in a great strike of apprentices one of their chief demands was that they be not fed on salmon more than three times a week. The richness of the fish supply of our eastern states in their early colonial days and for a considerable time thereafter is said to have exceeded our wildest imagination. Meehan ('17) quotes an early writer who said of the shad in the Susquehanna and Delaware Rivers: "They came in such vast multitudes that the still waters seemed filled with eddies, while the shallows were beaten into foam by them in their struggles to reach the spawning grounds." They swarmed every spring from mouth to headwaters of every river from Maine to Florida. Shad was undoubtedly the most important food fish in the early days of our nation; they were eaten fresh, and smoked and salted for winter use. During the spring runs people traveled long distances to shoal waters to obtain their winter's supply (Meehan, '17).

Along the Illinois River many years ago buffalo-fish afforded the chief marketable species. These were caught by farmers, fishermen, and others, and shipped by boat, principally to St. Louis. As no ice was used the fish frequently spoiled, or they were thrown away because the market was overloaded. Thus this great resource was depleted by careless and wasteful methods of catching and marketing (Bartlett, '17). For a brief discussion of more recent decrease of buffalo-fish in the Illinois River see Richardson, '13a, p. 409.

The Atlantic salmon once entered all the rivers of New England; now it is the most expensive fish on the market. Our Great Lakes once yielded whitefish in abundance, but now the number is exceptionally small in comparison. Some of our Pacific-coast fisheries are likewise being depleted. Every stream formerly yielded fish to small boys and old-men anglers. If any of these sources yielded half their original quantity it would now be counted a veritable fortune in fish.

Our fish resources have been depleted through neglect, carelessness, and the pollution of waters. Such as are still left are endangered by new projects and new pollutions. There has been too much bald scientific and business sophistry in the matter. Ichthyologists, biologists, engineers, sanitarians, industrial chemists, and business men, without consultation, cooperation, or critical analysis, have proceeded on the basis of their imperfect and fragmentary knowledge to draw inferences as to the effect of this or that on fishes. The inferences of some scientists are not especially more in keeping with an equitable decision relative to a policy favorable to the public interest than was the exclamation of a manufacturer when confronted with a law intended to stop his factory from polluting streams: "What! stop a great industry because of a few fish!" The pollutions of manufacturing plants and city sewage have greatly aggravated the depletion, or in some instances have completed the destruction, previously started by heedless fishermen; but the pollutions are far more serious than the initial injury because they preclude the possibility of easy recovery. We have all sinned alike until it becomes imperative that we take stock of our knowledge, now that we are under the pressure of numerous problems demanding immediate solution because of the great war. Some means of approximately measuring the harm which pollutions do, is needed at once. Our knowledge of the subject is incomplete and unorganized. A number of crucial questions have frequently called for answers in the past few months, and it is the purpose of this paper to state these problems, to emphasize the need for further definite investigation for their solution, and to give a general indication of the trend of existing data bearing on them. The general subject of the relation of aquatic animals to the physical and chemical conditions of their environment has only recently begun to receive systematic attention. (Birge and Juday, '11; Forbes and Richardson, '13; Shelford, '17, '18.) The tables here included are provisional and incomplete, but they indicate what kind of tables would be found highly useful were the data for them in hand, and they also indicate the pressing need for further investigation.

The writer wishes to express here his indebtedness to Mr. E. B. Powers and Mr. W. D. Hatfield for assistance in preparing this paper.

Nine Crucial Questions in Connection with Problems of Pollution in Relation to Useful Aquatic Animals

On the basis of the author's personal studies, an examination of the literature of the subject, and discussion with persons engaged in several related lines of investigation, an attempt is here made to point out means of answering nine crucial questions, relating to the survival, well-being, abundance, and quality of useful aquatic animals, which are intimately associated with the question of the economical use of wastes and the satisfactory disposal of such effluents as can not be worked up. But the final practical solution of so complex a problem calls for something more than a knowledge of the toxicity of wastes and the best methods for determining it, and insistence on the preservation of food and breeding grounds; it imperatively demands that in calculating values a standard shall be set which applies to the country as a whole rather than to a mere group of individuals (Austin, '17).

I. Is the animal used in testing the toxicity of a polluting substance one of representative sensitiveness?

The resistance of different useful aquatic animals to polluting substances varies greatly, as does also that of their living food. In the case of fish, for example, it is not sufficient to secure for making tests *any* fish that may be convenient. The fish used should be one of the more sensitive ones. The tests of toxicity must of course be of a character to determine means of affording protection to fish, but not to fish alone; the organisms on which they feed are commonly more sensitive than the fishes themselves.

The following table gives an estimate of the relative resistance of several widely distributed species of North American fishes. While it needs careful verification by new methods, it will serve as a rough provisional guide. It is based largely on death in waters containing little oxygen and much carbon dioxide. Since fishes rank differently in resistance according to the poison in which they are killed (Shelford, '17, p. 408), the immediate need for further investigation is obvious.

TABLE I

Indicating the relative resistance of a very sensitive minnow and of some common game-fishes of the eastern and central United States and of the goldfish. The resistance of the least resistant species is arbitrarily taken to be unity. (After Wells, '18, except the orange-spotted sunfish and the goldfish.)

Species of fish	Relative resistance	Species of fish	Relative resistance
Labidesthes sicculus (Brook silverside)	1.	*Ambloplites rupestris* (Rock bass)	10.
Moxostoma aureolum (Red-horse)	2.3	*Perca flavescens* (Yellow or American perch)	10.
Catostomus commersonii (Common sucker)	2.4	*Lepomis humilis* (Orange-spotted sunfish)	12.
Micropterus dolomieu (Small-mouthed black bass)	5.	*Carassius carassius* (Goldfish or Crucian carp)	12.
Micropterus salmoides (Large-mouthed black bass)	6.	*Lepomis cyanellus* (Blue-spotted sunfish)	15.
Pomoxis annularis (White crappie)	8.	*Ameiurus melas* (Black bullhead)	45.
Pomoxis sparoides (Black crappie, Calico bass)	8.		

Choice of Animals used for Tests.—The common suckers, *Catostomus commersonii* Lac. or *Moxostoma aureolum* Le S. are recommended as suitable fresh-water animals for tests. They are widely distributed, easy to obtain, and easy to recognize, and are representatively sensitive (Forbes and Richardson, '08). It is also comparatively easy to determine accurately when an individual is dead. Powers found that to touch the tip of the tail of a fish to HCl would determine whether or not it was dead. As a representative fish food fresh-water shrimps (Palaemonetes) may be used; they live all the time under water and fall over readily when overcome, and the movement of the gill-bailer can be readily seen and serves to show when death occurs. Shrimps are also good in marine work (Shelford, '16, '16a). *Hyalella knickerbockeri,* a common, small fresh-water amphipod, is perhaps one of the most widely distributed fish foods, and as it is sensitive it will serve as a test animal for fish foods.

Amount of Water.—Experience has shown that about one liter of water should be used for each two grams' weight of individuals tested. With non-volatile substances the diameter of the surface exposed should be about equal to the depth of the water (Marsh, '07; Shelford, '17; Wells, '18; Powers, '18). Volatile substances should be added to running water (Shelford and Allee, '13; Shelford, '17; Wells, '18).

Time to Death.—For comparisons of toxicities, concentrations which kill the animal in from fifty minutes to two hours should be used (Shelford, '17; Powers, '18); for the short experiments, the temperature should be constant; and for safety tests, the fish should live for about a month in the water. After two days in the small quantity of water, for long experiments the animal should be transferred to aquaria with two liters of water for each gram of fish (Marsh, '07).

II. What is the most sensitive stage in the life history of the test animal and of any useful animal associated with it?

Tests of the minimum quantity of poison which will prove fatal must be made on the most sensitive stage. The strength of a chain is the strength of its weakest link. After a fish or other animal of representative resistance has been chosen, the results of tests have little or no significance until *the most sensitive period* in the life history has been determined. Of what importance is it merely to know that three parts of naphthalene per million will kill an adult fish in one hour if some other stage is twice as sensitive? From this point of view only a little has been accomplished in the study of poisons; the most sensitive period is not known for a single species of which the entire life cycle has been definitely studied (Wells, '16). It has merely been determined that to nearly all toxic substances the younger or smaller fish, down to the smallest fry, are more sensitive than older ones, and Child ('15) has found that in the case of Tautogolabrus the resistance of the egg falls gradually from the time of fertilization to the time of hatching, when a slight rise occurs. His experiments were discontinued at this point. Investigation of the minimum quantities of substance which will prove detrimental is useless unless the experiment is conducted on the most sensitive stage. A twenty-gram rock bass may be fifty to one hundred times more resistant than the most sensitive stage in the egg or fry. This might be a safe guess for shrimps also. To meet Illinois problems alone, there is immediate need for a study of the entire life-cycle resistance of the suckers.

Choice of Stages to be tested and Frequency of Tests.—The early stages should be tested at very short intervals. Artificially fertilized eggs should be divided into lots and tested at intervals of fifteen minutes to several hours (Child, '15, pp. 412–416).

TABLE II

Showing differences in sensitivity of various stages of several marine and fresh-water animals. Most sensitive stage rated as 1. No basis for a comparison of the species. Whitley's results are not comparable with those of the others, as his experiments showed only abnormal development.

Species	Poison	Relative resistance of different stages		Observer
Starfish..........	KCN	Unfertilized egg	9.00	
		Blastula to gastrula......	1.00	Child ('15)
		Young bipinnaria	2.00	
Sea-urchin.......	KCN	Unfertilized egg	3.88	
		Early gastrula	1.00	" "
		Prepluteus	1.50	
Clam-worm.......	KCN	2–4 cell stage.............	18.00	
		Larva with 2 pairs of setae	1.00	" "
		Advanced larva	3.30	
Killifish..........	Phenyl urethane	2-cell stage	6.00	" "
		Hatching	1.00	
Tautogolabrus....	Phenyl urethane	15 min. after fertilization.	43.00	" "
		Heart beating	1.00	
		Newly hatched	1.25	
Plaice eggs.......	Acid	Fresh-laid	1.00	Whitley ('05)
	Acid	10 days old...............	10.00	
Plaice eggs.......	Alkali	Fresh-laid	1.00	" "
	Alkali	10 days old...............	2.00	
Rock bass........	CO_2 and low O_2	1.9 gram	1.00	Wells ('13)
		20–40 grams	5.00	
Common shiner...	CO_2 and low O_2	0.6 gram	1.00	" "
		21.0 grams	3.00	

Concentrations and Time to Death.—Tests should be made on each stage with five concentrations of the poison. Time-concentration curves should be plotted, reciprocal curves constructed (Krogh, '14; Powers, '18), and the comparisons made should be based on concentrations within which the rate of killing is regular.

III. When is the pollution most concentrated?

In fresh water, pollution will, as a rule, be most concentrated during seasons of drought or in extreme low-water in winter; but to this rule there are many exceptions. Pollutions which float will do most damage during storms or high winds. This source of danger is greatest in the sea.

Effect of Winter Ice.—Ice in winter prevents aeration and hinders circulation, and seems to have been responsible in Illinois for important losses of fish due to pollution (Hansen and Hilscher, '16, '16a).

Effect of Temperature.—Many poisons are more toxic at high temperature than at low (Warren, '00). Results soon to be published by Powers confirm Warren's conclusions. Experiments should generally be carried on when the water in question is at the usual seasonal temperature, though some tests should always be made at its maximum temperature. Some of the relative-resistance work on adult fishes at different seasons of the year may have been vitiated to some extent by too little regard to the temperature factor, thus yielding somewhat exaggerated differences of resistance in the comparisons made (Wells, '16). Temperature has direct effects also (Wells, '14).

Effect of Oxygen.—An abundant supply of dissolved oxygen reduces the toxicity of some substances—of CO_2, for example (Wells, '13; Shelford, '18b).

IV. What is the toxicity of untreated polluting effluents; of each residual of processes of partial recovery; or of treatment by additions to the effluent?

One essential in dealing with pollution problems lies in the determination of the toxicity of the various constituents of the polluting substance and of the wastes or residues resulting either from operations—present or prospective—for the recovery of useful substances or from methods of treating the effluent. This is imperative, for partial-recovery methods may give rise to substances as residues or secondary by-products which are as toxic as the original waste, or even more so. As a case in point I may mention a personal study of a large series of representative constituents of gas wastes which I began in 1914. This investigation showed that all the essential components are so highly toxic that no method of *partial* recovery can be relied upon to protect fishes. The least suspected substances, some rated as insoluble, were among the most toxic —for example, CO, benzene, and naphthalene (Shelford, '17; Wells, '18).

The proposed plan of treating the sewage of Boston and Chicago and other cities of more than 50,000 inhabitants by the Miles acid process (Weston, '16) in order to recover grease, ammonia, and glycerine, and to leave a strongly acid effluent which, in the case of Boston and other coast towns, would provide a sterile medium for oyster-beds, is a matter demanding very careful investigation, since acids $\left(\frac{M}{1000}\right)$ are fatal, or essentially so, to the eggs of such marine animals as have been tested with them. Moore and others ('05), in experiments with acids and alkalies found that the addition of a very little acid checked or stopped development in sea-urchin's eggs, while much more alkali could be used without ill effects. This conclusion was confirmed by Whitley's experiments with the eggs of the plaice, one of the flatfishes. After using several acids and several alkalies Whitley concluded ('05) that the deleterious effect on these eggs was due to hydrogen and hydroxyl ions. The earlier work of Loeb ('98, '04) as well as that of Medes ('18) showed the same thing. For the relative toxicities of salts and acids see Table III; note that HCl is 404 times as toxic as common salt.

The addition of acid to water is accompanied by the liberation of CO_2. This may be released from carbonates in quantities very harmful to fishes. Methyl-orange acidity is nearly always fatal to them (Marsh, '07; Wells, '15). In all such cases the precise hydrogen ion concentration should be determined, but the concentration fatal to the various stages must not be neglected. Limestone is often used to neutralize acid, sometimes to doubtful advantage. Table III shows the relative toxicity of a number of different compounds in distilled water. The table is incomplete and based on the work of several authors. Further investigation is needed along this line.

Table III

Showing the relative toxicity, on a basis of weight, of different substances when added to distilled water, which was used except in the experiments marked (S). (KM) signifies according to Kahlenberg and Mehl, '01; (KH), according to Koenig and Hasenbaeumer, '02; (Ms), Marsh, '07; (M), Mathews, '04; (P), Powers, '18; (S) Shelford, '17; (W), Wells, '15a. The toxicities of sulfurous acid and its salts were calculated on the basis of the similarity of the resistance of some of the wild fishes and goldfish. The figures are only approximate for results by the same author. Comparisons between the results of different authors show some striking differences, but the great toxicity of acids and alkalies is evident. The higher the figure the greater the toxicity of the substance. All are compared with common salt, which is taken as 100 for all.

Animals tested	Poison		Chlorides (Cl)	Sulfates (SO_4)	Nitrates (NO_3)	Carbonates (CO_3)	Bicarbonates (HCO_3)	Hydroxides (OH)	Sulfites (SO_3)	Acid sulfites (HSO_3)
Fresh-water fishes	(Acids)	H	40,400(KM)	15,000(KM)	23,000(KM)	3,700(S)	....	....	11,700(KH) 14,000(S)†	
(Based on amount required to kill in 45 min. to 3 hours)	(Salts)	Na	100(P)	....	54(P)					
		K	50(P)							
		Ca	59(P)	....	118(P)	....	....	15,000(Ms*)	22,000(KH)	10,000(KH)
		Br	60(P)							
		Mg	77(P)	15(KM)	105(P)					
		NH_4	300(S) 65(P)	450(S) 400(W)	232(P)	....	....	30,000(S)		
Marine Fundulus eggs	(Acids)	H	249,500(M)							
(Based on least fatal dose)	(Salts)	Na	100(M)	97(M)	69(M)	....	138(M)	14,610(M)		
		K	70(M)	....	38(M)	....	....	6,200(M)		
		Ca	185(M)							
		Ba	56(M)	....	....	....	....	8,100(M)		
		Mg	113(M)							
		NH_4	88(M)							
		Sr	53(M)							

*Least fatal dose to trout; not comparable, but of right order of magnitude. †SO_2.

When these substances are introduced in water in which salts are already in solution the results are sometimes not in agreement with those obtained when the substances are in solution alone. CO_2 renders some salts less toxic. One salt often renders another less toxic or may neutralize its effect. On the other hand, combinations are sometimes more toxic than the individual constituents alone. Wells found that a little HCl reduced the toxicity of common salt to about one-third. Ammonia salts are harmless to some fishes in the absence of carbonates but toxic in their presence. This subject is too complicated and knowledge too meager to justify inferences as to the effect of mixtures of salts in streams. Organic compounds are often more toxic in the presence of salts. For data on this subject see Clowes, '17; Lillie, '12; Loeb, '06, '12; Osterhout, '14, '14a, '16; Powers, '18; and Spaeth, '17. Osterhout ('14a) has constructed important curves showing some of the most antagonistic mixtures of salts.

The toxicity of residuals of partial recovery may be determined directly if the process of treatment is in operation; if not, and if the character of the residuals is not known it is necessary to take a series of the representative constituents in a pure state, and to make tests of their toxicity. When this has been done it will usually be possible to foresee the toxicity of any residual of a proposed method of treatment (Shelford, '17).

Determination of Hydrogen Ion Concentration; that is, its Acidity or Alkalinity.—This is best done by indicators (McClendon, '16; Clark and Lubs, '17). The addition of substances to sea water demands some special attention, as precipitation of calcium and magnesium carbonates precedes any marked increase of hydroxyl ions due to the addition of alkalies (Whitley, '05; Haas, '16). They settle out as a white precipitate.

Treatment of Water during Low-water Stages.—Aeration of the effluent after considerable dilution will always help to render it less dangerous. Some of the aerating devices used in the activated-sludge process of sewage treatment will serve. (Porter, '17; Bartow, '17.)

V. Do animals turn back from the polluting substance and thus escape destruction; or do they swim into it and die?

Fresh-water fishes swim into nearly all coal-gas waste constituents, and on returning to clear water avoid it because intoxicated, and die. This fact of course increases many times the danger from these substances. Fishes often react in this way to SO_2, which may be a source of danger in the Miles acid process. The most important reactions of this kind are probably those of fish which run on shore. The great sensitiveness of herring in reactions to small quantities of CO_2 in sea water suggests that the erratic runs of this fish on our Pacific coast may be due to some such negative reaction. Likewise the great historical failure and alleged migration of the herring in Europe which contributed to the decline of the Baltic towns of the Hanseatic League and to the rise of Amsterdam may have been due to a similar cause.

The acids from munition works have attracted attention of late. An effluent composed of 0.13 to 0.4 per cent. of acid—a mixture of 2 parts of sulfuric acid and 1 part of nitric acid—is discharged by guncotton works. This acid effluent flowing into the brackish waters of the coast of New Jersey repelled the killifishes, on which the keeping down of mosquitoes depends. It was proposed to treat the acid effluent with lime, and the question of the effect of the calcium nitrate on the fishes became a problem for immediate solution.* Similar problems are arising in connection with inland rivers. Large quantities of such acid is now being run into the Sangamon River by munition works at Springfield, Ill., and into various other waters of this state.

The Gradient Tank.—The gradient tank in which experiments designed to answer question V are performed, should be twice as wide, three times as deep and twenty times as long as the length of the fishes to be tested (Shelford and Allee, '13; Powers, '14; Wells, '15). Where the density of the water introduced at the two ends is different inclined screens should be used (Shelford and Powers, '15, p. 327).

Temperature.—It is necessary to see that the temperature of the water at the two ends of the tank does not differ more than 0.2°C. (Wells, '14; Shelford and Powers, '15).

VI. Do polluting substances cover the bottom and make conditions unfavorable for eggs?

The majority of important fresh-water animals—mussels, which furnish pearl for buttons, whitefish, bass, sunfish, etc.—are dependent on the bottom for breeding, living conditions, or food. For example, bare clean terrigenous bottom is necessary as a resting-place for eggs of the whitefish of the Great Lakes (Clark, '10). It breeds in 8–25 meters of water. Many of the important breeding-grounds in the Great Lakes have been ruined, or at least rendered unusuable for a long time to come, by the accumulation of slowly putrescing sawdust, water-logged wood, etc. (Clark, '10). In Grand Traverse Bay, Lake Michigan, in 1871, salmon ova were discovered to be diseased and decaying, with particles of sawdust adhering to them (Milner, '74). Tarry material often covers bottoms and destroys life there. In the case of marine animals such as herring, clams, and mussels, similar serious results may occur.

Bottom-sampling.—The Petersen bottom-sampler is the best instrument to be used in deep water (Murray and Hjort, '12, p. 785). For shallow-water methods see Baker, '16. If the contaminating substances are covering breeding bottoms of bare sand and gravel they are dangerous (Knight, '03).

Bottom Index Organisms.—The presence of gilled snails of the genera Pleurocera and Goniobasis in fresh water indicates clean bottoms. Various other organisms usually indicate pollution with sewage (Forbes and Richardson, '13).

* For this information the writer is indebted to R. S. Patterson, of the New Jersey Mosquito Commission.

Bottom Oxygen and Carbon Dioxide.—Samples should be taken from the bottom. The oxygen content of water over breeding grounds should be about 4 c.c. per liter, and CO_2 probably not more than 1–5 c.c. per liter, the precise amount depending on the fish species present (Shelford, '14; Wells, '13, '15, '15a). The effect of CO_2 on the eggs of fresh-water fishes has not been fully determined (Ransom, '66). (Milner, '74; Anthony, '08; Paige, '08; Birge and Juday, '11; Shelford, '11, '11a, '11b; Forbes and Richardson, '13; Wells, '13.)

Conditions favoring Fungi.—It is probable that acidity, that is, much CO_2, and bad aeration favor fungus attack. Such attacks usually occur on eggs or adults; not on fry (Clinton, '93; Dean, '93; Richardson, '13).

VII. If the supply of useful animals is depleted will recovery be rapid or slow?

Petersen and Jensen found that if the flora and fauna were removed from marine bottoms useful animals such as oysters can not again live on them until a series or succession of plants and animals has prepared the way. (Petersen and Jensen, '11; Mőbius, '83.) The same is true of fishes in fresh water. A body of water deprived of all its vegetation, with the associated animals, requires much time for recovery. It is not simply the useful animals that must be taken into consideration, but the entire association (Adams, '09; Shelford, '10, '11, '11a, '11b).

VIII. Can correct decisions be reached without investigation of individual cases which arise?

Decisions relative to all the preceding points must usually be reached on the ground. Waters differ in their capacity to neutralize the effects of effluents, in the maximum and minimum flow, and in their dissolved content. Samples of water should be taken with reference to the particular animal-problem in hand. Carbon dioxide and oxygen determinations should be made on the ground, and at least a small amount of observation is indispensable. Mere office decisions, made at a distance and based upon report and inferences, are dangerous. The "antagonisms" of poisons, discussed on page 33, make decision without experiments unwise.

IX. What is the real value of the waste when the amount of the damage which it causes is added to its commercial value?

One continually hears it said that the recovery of this or that waste product does not pay; that this is an all-sufficient reason for not recovering it—and the matter is usually dismissed forthwith. We need an entirely new view-point. The value of any waste product is its commercial value, when properly recovered, plus the amount of loss it occasions when unrecovered. Practically all kinds of waste may be made into something useful (Koller, '15; Weston, '16; Feilding, '17). The recovery of grease from sewage or garbage might not pay under market conditions, but if the grease so recovered will prevent the national supply from giving out it should be recovered by all means. It has been estimated (see *Oil, Paint and Drug Reporter*, '18 and '18a) that the sewage of ninety-seven cities of more than 50,000 inhabitants, treated by the Miles acid process, would yield per year as follows:

Fertilizer	97,393,680 tons
Ammonia	4,869,684 tons
Grease	25,780,680 tons
Glycerine	1,289,039 tons

Recovery plants have not been installed, however, because critics of the conservation plan maintain that the profits will be less than its friends have predicted. As has been true in most other cases, calculations of the cost of suitable recovery plants and of the value of recovered products have been made with only minor regard to public health, and with little reference to the damage which the remaining effluent may do to fishes. In correct calculations the value of the recovered products and the benefits to public health would both be regarded as credits. The dangers or benefits to fisheries from the residual acid effluent of the Miles process should also be considered. This effluent is 50 parts per million acid. Either sulfuric acid or sulfur dioxide may be used in the process. Sulfur dioxide and salts of sulfurous acid (Phelps, '09) are probably more toxic to fishes than sulfuric acid and its salts (see Table III). The acid should be neutralized if present in dangerous concentrations, and the cost of reducing the acidity of the effluent balanced against fisheries protected thereby.

LITERATURE CITED

Adams, C. C.

'09. An ecological survey of Isle Royale, Lake Superior. Biol. Surv. Mich., pp. 1–57; 121–154; 157–203; 389–395.

Anthony, R.

'08. The cultivation of the turbot. Bull. U. S. Bur. Fisheries, 28 (Pt. 2) : 861–870.

Austin, F. C.

'17. Utilization of fish waste. Canadian Fisherman, 4 : 263.

Baker, F. C.

'16. The relation of mollusks to fish in Oneida Lake. Tech. Pub., No. 4, N. Y. State Coll. Forestry.

Bartlett, S. P.

'17. Fish waste, past and present. Trans. Am. Fish. Soc., 47 : 22–27.

Bartow, Edward

'17. Purification of sewage by aeration in the presence of activated sludge. III. Indust. and Eng. Chem., 9 : 845–847.

Birge, E. A., and Juday, Chancey

'11. The inland lakes of Wisconsin—the dissolved gases of the water and their biological significance. Wis. Geol. and Nat. Hist. Surv., Bull. No. XXII; Sci. Ser., No. 7.

Child, C. M.

'15. Senescence and rejuvenescence. University of Chicago Press, Chicago.

Clark, F. N.

'10. A plan for promoting the whitefish production of the Great Lakes. Bull. U. S. Bur. Fisheries, 28 : 637–643.

Clark, W. M., and Lubs, H. A.

'17. The colorimetric determination of hydrogen ion concentration and its applications in bacteriology. Jour. Bact., 2 : 1–34; 109–136; 191–236.

Clinton, G. P.

'93. Observations and experiments on Saprolegnia infesting fish. Bull. U. S. Fish Comm., 13 : 163–172.

Clowes, G. H. A.

'17. Antagonistic electrolytes and jelly-formation Jour. Biol. Chem., 29 : viii–ix.

'17a. Electrolytes and anaphylaxis. Jour. Biol. Chem., 29 : ix–xi.

Dean, Bashford.
'93. Recent experiments in sturgeon hatching on the Delaware River. Bull. U. S. Fish Comm., 13 : 335–339.

Feilding, J. B.
'17. Fisheries waste: its use and value. Canadian Fisherman, 4 : 272–274.

Forbes, S. A., and Richardson, R. E.
'08. The fishes of Illinois. Nat. Hist. Surv. Ill., Vol. 3.
'13. Studies of the biology of the upper Illinois River. Bull. Ill. State Lab. Nat. Hist., 9 : 480–574.

Hansen, Paul, and Hilscher, Ralph
'16. Pollution of Vermilion River at and below Streator. Univ. of Ill. Bull., Vol. 14, No. 5; Water Surv. Ser., No. 13 : 234–250.
'16a. Investigation of the destruction of fish in Sangamon River below Springfield. Univ. of Ill. Bull., Vol. 14, No. 5; Water Surv. Ser., No. 13 : 251–255.

Haas, A. R.
'16. The effect of the addition of alkali to sea water upon the hydrogen ion concentration. Jour. Biol. Chem., 26 : 515–517.

Kahlenberg, L. and Mehl, H. F.
'01. Toxic action of electrolytes upon fishes. Jour. Phys. Chem., 5 : 113–132.

Knight, A. P.
'03. Sawdust and fish life. Trans. Can. Inst., 7 : 425–466.

Kőnig, J., and Hasenbăumer, J.
'02. Einfluss von schwefliger Săure auf Pflanzen und Fische. Fűhling's landw. Zeit., 51 : 853–857; 893–895.

Koller, Theodor
'15. The utilization of waste products. (Translated from second revised German edition.) Scott, Greenwood & Son, London; D. Van Nostrand Co., New York.

Krogh, A.
'14. On the influence of the temperature on the rate of embryonic development. Zeit. f. Allg. Phys., 16 : 163–177.

Lillie, R. S.
'12. Antagonism between salts and anaesthetics. I. Am. Jour. Physiol., 29 : 372–397.

Loeb, J.
'98. Uber den Einfluss von Alkalien und Săuren auf die embryonale Entwickelung und das Wachsthum. Archiv Entw. Mech. d. Org., 7 : 631–641.
'04. On the influence of the reaction of the sea-water on the regeneration and growth of tubularians. Univ. Calif. Pub., Physiology, 1 : 139–147.

'06. Dynamics of living matter. Columbia Univ. Biology Series, VIII. Macmillan Co., Agents.

'12. The mechanistic conception of life. Univ. of Chicago Press.

McClendon, J. F.

'16. Hydrogen and hydroxyl ion concentration in physiology and medicine. Medical Rev. of Rev., 22 : 333–365.

Marsh, M. C.

'07. The effect of some industrial wastes on fishes. U. S. Geol. Surv., Water-Supply Paper 192 : 337–348.

Mathews, A. P.

'04. The relation between solution tension, atomic volume, and the physiological action of the elements. Am. Jour. Physiol., 10 : 290–323.

Medes, Grace

'18. A study of the causes and the extent of variations in larvae of *Arbacia punctulata*. Jour. Morph., 30 : 317–432.

Meehan, W. E.

'17. The battle for the fishes. Canadian Fisherman, 4 : 275–279.

Milner, J. W.

'74. The Fisheries of the Great Lakes. Report on the result of inquiries prosecuted in 1871 and 1872. Rep. U. S. Fish Comm. for 1872–73 : 1–75.

Möbius, K.

'83. The oyster and oyster-culture. Rep. U. S. Fish Comm. for 1880 : 683–747.

Moore, B., Roaf, H. E., and Whitley, E.

'05. On the effects of alkalies and acids, and of alkaline and acid salts, upon growth and cell division in the fertilized eggs of *Echinus esculentus*. A study in relationship to the causation of malignant disease. Proc. Soc. London, 77 (Ser. B) : 102–136.

Murray, J., and Hjort, J.

'12. The Depths of the Ocean. Macmillan & Co., London.

Oil, Paint and Drug Reporter

'18. Millions of tons of fertilizer and grease available from waste [Miles acid process]. 93 (No. 2) : 67.

'18a. Government experts to test Miles process to recover sewage grease. 93 (No.5) : 28.

Osterhout, W. J. V.

'14. The measurement of antagonism. Bot. Gaz., 58 : 272–276.

'14a. The forms of antagonism curves as affected by concentration. Bot. Gaz., 58 : 367–371.

'16. Antagonism and Weber's law. Science, N. Ser., 44 : 318–320.

Paige, C. L.
'08. A method of cultivating rainbow trout and other salmonids. Bull. U. S. Bur. Fisheries, 28 (Pt. 2) : 781–787.

Petersen, C. G. J., and Jensen, P. B.
'11. Valuation of the sea. I. Animal life of the sea-bottom, its food and quantity. Rep. Danish Biol. Station, 20 : 1–76.

Phelps, E. B.
'09. The pollution of streams by sulphite pulp waste: a study of possible remedies. U. S. Geol. Surv., Water-Supply Paper 226.

Porter, J. E.
'17. The activated sludge process of sewage treatment: a bibliography of the subject. Printed by the General Filtration Co., Inc., Rochester, N. Y.

Powers, E. B.
'14. The reaction of crayfishes to gradients of dissolved carbon dioxide and acetic and hydrochloric acids. Biol. Bull., 27 : 177–200.
'18. The goldfish (*Carassius carassius* L.) as a test animal in the study of toxicity. Ill. Biol. Mon., 4 : No. 2.

Ransom, W. H.
'66. On the conditions of the protoplasmic movements in the eggs of osseous fishes. Jour. Anat. and Physiol., 1 : 237–245.

Richardson, R. E.
'13. Observations on the breeding of the European carp in the vicinity of Havana, Illinois. Bull. Ill. State Lab. Nat. Hist., 9 : 387–404.
'13a. Observations on the breeding habits of fishes at Havana, Illinois, 1910 and 1911. Bull. Ill. State Lab. Nat. Hist., 9 : 409.

Shelford, V. E.
'10. Ecological succession of fish and its bearing on fish culture. Trans. Ill. Acad. Sci., 3 : 108–110.
'11. Ecological succession. I. Stream fishes and the method of physiographic analysis. Biol. Bull., 21 : 9–35.
'11a. Ecological Succession. II. Pond fishes. Biol. Bull., 21 : 127–151.
'11b. Ecological succession. III. A Reconnaissance of its causes in ponds with particular reference to fish. Biol. Bull., 22 : 1–38.
'14. Suggestions as to indices of the suitability of bodies of water for fishes. Trans. Am. Fisheries Soc., 44 : 27–32.
'16. Physiological characters of marine animals from different depths. Trans. Am. Fisheries Soc., 45 : 191–197.
'16a. Physiological differences between marine animals from different depths. Puget Sound Marine Station Pub., 1 : 157–174.

'17. An experimental study of the effects of gas waste upon fishes, with especial reference to stream pollution. Bull. Ill. State Lab. Nat. Hist., 11 : 381–412.

'18. Conditions of existence. Ward and Whipple's "Fresh-Water Biology," Chapter II, pp. 21–60. John Wiley & Sons, New York.

'18a. Physiological problems in the life-histories of animals, with particular reference to their seasonal appearance. Am. Nat., 52 : 129–154.

'18b. Apparatus for giving a constant flow of oxygen-free water. Bull. Ill. State Lab. Nat. Hist., 11 : 573–575.

Shelford, V. E., and Allee, W.

'12. An index of fish environments. Science, N. Ser., 36 : 76–77.

'13. The reactions of fishes to gradients of dissolved atmospheric gases. Jour. Exper. Zool., 14 : 207–266.

Shelford, V. E., and Powers, E. B.

'15. An experimental study of the movements of herring and other marine fishes. Biol. Bull., 28 : 315–334. Reprint in Fishing Gazette, 13 (No. 13) : 385–388; 13 (No. 14) : 418–420.

Spaeth, R. A.

'17. The physiology of the chromatophores of fishes. II. Responses to alkaline earths and to certain neutral combinations of electrolytes. Am. Jour. Physiol., 42 : 595–596.

Warren, E.

'00. On the reaction of *Daphnia magna* (Straus) to certain changes in its environment. Quart. Jour. Micr. Sci., 43 : 199–224.

Wells, M. M.

'13. The resistance of fishes to different concentrations and combinations of oxygen and carbon dioxide. Biol. Bull., 25 : 323–347.

'14. The resistance and reactions of fishes to temperature. Trans. Ill. Acad. Sci. 7 : 48–59.

'15. Reactions and resistance of fishes in their natural environment to acidity, alkalinity and neutrality. Biol. Bull. 29 : 221–257.

'15a. The reactions and resistance of fishes in their natural environment to salts. Jour. Exper. Zool., 19 : 243–283.

'16. Starvation and the resistance of fishes to lack of oxygen and to KCN. Biol. Bull., 31 : 441–452.

'18. The reactions and resistance of fishes to carbon dioxide and carbon monoxide. Bull. Ill. State Lab. Nat. Hist., 9 : 557–571.

Weston, R. S.

'16. Tests of a new process of sewage purification with grease recovery and apparent profit. Am. Jour. Pub. Health, 6 : 334–343.

Whitley, Edward
'05. A note on the effect of acid, alkali, and certain indicators in arresting or otherwise influencing the development of the eggs of *Pleuronectes platessa* and *Echinus esculentus*. Proc. Roy. Soc. London, 77 (Ser. B) : 137–149.