BIOLOGY OF WATER POLLUTION

A Collection of Selected Papers on Stream Pollution,
Waste Water, and Water Treatment

Compiled
by

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PREFACE

Water users are becoming more and more concerned with the abatement of pollution. Accelerated population and industrial growth has brought many persons into intimate contact with problems relating to water degradation that is associated with municipal, industrial, or agricultural wastes, or combinations of these. Thus, the problems of waste disposal and their reasonable solution are today the concern of all. It is apparent that problems attendant to waste disposal and water treatment are increasing. Most people fully appreciate that streams, lakes, and estuarine waters remain static in quantity.

With increased concern for America's water resources, the populace is demanding accelerated programs for the abatement of pollution, and this requires an increased number of personnel trained in and cognizant of environmental science.

Science is common sense based upon the experiences of man. Scientific literature is a record of these experiences. With the growth of the aquatic sciences, the literature has become voluminous, creating an information retrieval problem. In addition, many of the earlier writings were published in limited editions and some in not readily available journals. Today many are not readily available to the scientist who does not have access to a large, long established library.

This book of selected publications on Biology of Water Pollution, Water Treatment, and Sewage and Industrial Waste Treatment contains some of the many excellent and basic pertinent biological papers that have been commonly inaccessible to the contemporary investigator. These papers are often quoted (sometimes incorrectly) and are a portion of the "foundation" upon which modern aquatic ecological scientific thought and decisions are often based in summating water pollution control investigations.

This compiled collection will be of assistance in three phases of water pollution abatement: (1) It will provide a technical service to the aquatic ecologist through the assemblage of informative literature; (2) it will illustrate many of the concepts upon which regulations have been formulated for the protection of aquatic life; (3) it will aid in the training of new environmental scientists to meet today's and tomorrow's personnel needs in the conservation of our Nation's natural resources.

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Cincinnati, Ohio
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Chapter I

GENERAL BACKGROUND OF BIOLOGICAL ASPECTS OF WATER POLLUTION

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THE LAKE AS A MICROCOSM*

Stephen A. Forbes

A lake is to the naturalist a chapter out of the history of a primeval time, for the conditions of life there are primitive, the forms of life are, as a whole, relatively low and ancient, and the system of organic interactions by which they influence and control each other has remained substantially unchanged from a remote geological period.

The animals of such a body of water are, as a whole, remarkably isolated -- closely related among themselves in all their interests, but so far independant of the land about them that if every terrestrial animal were suddenly annihilated it would doubtless be long before the general multitude of the inhabitants of the lake would feel the effects of this event in any important way. It is an islet of older, lower life in the midst of the higher, more recent life of the surrounding region. It forms a little world within itself -- a microcosm within which all the elemental forces are at work and the play of life goes on in full, but on so small a scale as to bring it easily within the mental grasp.

Nowhere can one see more clearly illustrated what may be called the sensibility of such an organic complex, expressed by the fact that whatever affects any species belonging to it, must have its influence of some sort upon the whole assemblage. He will thus be made to see the impossibility of studying completely any form out of relation to the other forms; the necessity for taking a comprehensive survey of the whole as a condition to a satisfactory understanding of any part. If one wishes to become acquainted with the black bass, for example, he will learn but little if he limits himself to that species. He must evidently study also the species upon which it depends for its existence, and the various conditions upon which these depend. He must likewise study the species with which it comes in competition, and the entire system of conditions affecting their prosperity; and by the time he has studied all these sufficiently he will find that he has run through the whole complicated mechanism of the aquatic life of the locality, both animal and vegetable, of which his species forms but a single element.

It is under the influence of these general ideas that I propose to examine briefly to-night the lacustrine life of Illinois, drawing my data from collections and observations made during recent years by myself and my assistants of the State Laboratory of Natural History.

The lakes of Illinois are of two kinds, fluviatile and water-shed. The fluviatile lakes, which are much the more numerous and important, are appendages of the river systems of the state, being situated in the river bottoms and connected with the adjacent streams by periodical overflows. Their fauna is therefore substantially that of the rivers themselves, and the two should, of course, be studied together.

They are probably in all cases either parts of former river channels, which have been cut off and abandoned by the current as the river changed its course, or else are tracts of the high-water beds of streams over which, for one reason or another, the periodical deposit of sediment has gone on less rapidly than over the surrounding area, and which have thus come to form depressions in the surface which retain the waters of overflow longer than the higher lands adjacent. Most of the numerous "horseshoe lakes" belong to the first of these varieties, and the "bluff-lakes," situated along the borders of the bottoms, are many of them examples of the second.

These fluviatile lakes are most important breeding grounds and reservoirs of life, especially as they are protected from the filth and poison of towns and manufactories by which the running waters of the state are yearly more deeply defiled.

The amount and variety of animal life contained in them as well as in the streams related to them is extremely variable, depending chiefly on the frequency, extent, and duration of the spring and summer overflows. This is, in fact, the characteristic and peculiar feature of life in these waters. There is perhaps no better illustration of the methods by which the flexible system of organic life adapts itself, without injury, to widely and rapidly fluctuating conditions. Whenever the waters of the river remain for a long time far beyond their banks, the breeding grounds of fishes and other animals are immensely extended, and their food supplies increased to a corresponding degree. The slow or stagnant backwaters of such an overflow afford the best situations possible for the development of myriads of Entomostraca, which furnish, in turn, abundant food for young fishes of all descriptions. There thus results an outpouring of life -- an extraordinary multiplication of nearly every species, most prompt and rapid, generally speaking, in such as have

* This paper, originally read February 25, 1887, to the Peoria Scientific Association (now extinct), and published in their Bulletin, was reprinted many years ago by the Illinois State Laboratory of Natural History in an edition which has long been out of print. A single copy remaining in the library of the Natural History Survey is used every year by classes in the University of Illinois, and a professor of zoology in a Canadian university borrows a copy regularly from a Peoria library for use in his own classes. In view of this long-continued demand and in the hope that the paper may still be found useful elsewhere, it is again reprinted, with trivial emendations, and with no attempt to supply its deficiencies or to bring it down to date.

the highest reproductive rate, that is to say, in those which produce the largest average number of eggs and young for each adult.

The first to feel this tremendous impulse are the protophytes and Protozoa, upon which most of the Entomostraca and certain minute insect larvae depend for food. This sudden development of their food resources causes, of course, a corresponding increase in the numbers of the latter classes, and, through them, of all sorts of fishes. The first fishes to feel the force of this tidal wave of life are the rapidly-breeding, non-predaceous kinds; and the last, the game fishes, which derive from the others their principal food supplies. Evidently each of these classes must act as a check upon the one preceding it. The development of animalcules is arrested and soon sent back below its highest point by the consequent development of Entomostraca; the latter, again, are met, checked, and reduced in number by the innumerable shoals of fishes with which the water speedily swarms. In this way a general adjustment of numbers to the new conditions would finally be reached spontaneously; but long before any such settled balance can be established, often of course before the full effect of this upward influence has been exhibited, a new cause of disturbance intervenes in the disappearance of the overflow. As the waters retire, the lakes are again defined; the teeming life which they contain is restricted within daily narrower bounds, and a fearful slaughter follows; the lower and more defenseless animals are penned up more and more closely with their predaceous enemies, and these thrive for a time to an extraordinary degree. To trace the further consequences of this oscillation would take me too far. Enough has been said to illustrate the general idea that the life of waters subject to periodical expansions of considerable duration, is peculiarly unstable and fluctuating; that each species swings, pendulum-like but irregularly, between a highest and a lowest point, and that this fluctuation affects the different classes successively, in the order of their dependence upon each other for food.

Where a water-shed is a nearly level plateau with slight irregularities of the surface many of these will probably be imperfectly drained, and the accumulating waters will form either marshes or lakes according to the depth of the depressions. Highland marshes of this character are seen in Ford, Livingston, and adjacent counties,* between the headwaters of the Illinois and Wabash systems and an area of water-shed lakes occurs in Lake and McHenry counties, in northern Illinois.

The latter region is everywhere broken by low, irregular ridges of glacial drift, with no rock but boulders anywhere in sight. The intervening hollows are of every variety, from mere sink-holes, either dry or occupied by ponds, to expanses of several square miles, forming marshes or lakes.

This is, in fact, the southern end of a broad lake belt which borders Lakes Michigan and Superior on the west and south, extending through eastern and northern Wisconsin and northwestern Minnesota, and occupying the plateau which separates the headwaters of the St. Lawrence from those of the Mississippi. These lakes are of glacial origin, some filling beds excavated in the solid rock, and others collecting the surface waters in hollows of the drift. The latter class, to which all the Illinois lakes belong, may lie either parallel to the line of glacial action, occupying valleys between adjacent lateral moraines, or transverse to that line and bounded by terminal moraines. Those of our own state all drain at present into the Illinois through the Des Plaines and Fox; but as the terraces around their borders indicate a former water-level considerably higher than the present one it is likely that some of them once emptied eastward into Lake Michigan. Several of these lakes are clear and beautiful sheets of water, with sandy or gravelly beaches, and shores bold and broken enough to relieve them from monotony. Sportsmen long ago discovered their advantages and club-houses and places of summer resort are numerous on the borders of the most attractive and easily accessible. They offer also an unusually rich field to the naturalist, and their zoology and botany should be better known.

The conditions of aquatic life are here in marked contrast to those afforded by the fluviatile lakes already mentioned. Connected with each other or with adjacent streams only by slender rivulets, varying but little in level with the change of the season and scarcely at all from year to year, they are characterized by an isolation, independence, and uniformity which can be found nowhere else within out limits.

Among these Illinois lakes I did considerable work during October of two successive years, using the sounding line, deep-sea thermometer, towing net, dredge, and trawl in six lakes of northern Illinois, and in Geneva Lake, Wisconsin, just across the line. Upon one of these Illinois lakes I spent a week in October, and an assistant, Prof. H. Garman, now of the University, spent two more, making as thorough a physical and zoological survey of this lake as was possible at that season of the year.

I now propose to give you in this paper a brief general account of the physical characters and the fauna of these lakes, and of the relations of the one to the other; to compare, in a general way, the animal assemblages which they contain with those of Lake Michigan -- where also I did some weeks of active aquatic work in 1881 -- and with those of the fluviatile lakes of central Illinois; to make some similar comparisons with the lakes of Europe; and, finally, to reach the subject which has given the title to this paper -- to study the system of natural interactions by which this mere collocation of plants and animals has been organized as a stable and prosperous community.

First let us endeavor to form the mental picture. To make this more graphic and true to the facts, I will describe to you some typical lakes among those in which we worked; and will then do what I can to furnish you the materials for a picture of the life that swims and creeps and crawls and burrows and climbs through the water, in and on the bottom, and among

* All now drained and brought under cultivation.

the feathery water-plants with which large areas of these lakes are filled.

Fox Lake, in the western border of Lake county, lies in the form of a broad irregular crescent, truncate at the ends, and with the concavity of the crescent to the northwest. The northern end is broadest and communicates with Petite Lake. Two points projecting inward from the southern shore form three broad bays. The western end opens into Nippisink Lake, Crab Island separating the two. Fox River enters the lake from the north, just eastward of this island, and flows directly through the Nippisink. The length of a curved line extending through the central part of this lake, from end to end, is very nearly three miles, and the width of the widest part is about a mile and a quarter. The shores are bold, broken, and wooded, except to the north, where they are marshy and flat. All the northern and eastern part of the lake was visibly shallow -- covered with weeds and feeding water-fowl, and I made no soundings there. The water there was probably nowhere more than two fathoms in depth, and over most of that area was doubtless under one and a half. In the western part, five lines of soundings were run, four of them radiating from Lippincott's Point, and the fifth crossing three of these nearly at right angles. The deepest water was found in the middle of the mouth of the western bay, where a small area of five fathoms occurs. On the line running northeast from the Point, not more than one and three fourths fathoms is found. The bottom at a short distance from the shores was everywhere a soft, deep mud. Four hauls of the dredge were made in the western bay, and the surface net was dragged about a mile.

Long Lake differs from this especially in its isolation, and in its smaller size. It is about a mile and a half in length by a mile in breadth. Its banks are all bold except at the western end, where a marshy valley traversed by a small creek connects it with Fox Lake, at a distance of about two miles. The deepest sounding made was six and a half fathoms, while the average depth of the deepest part of the bed was about five fathoms.

Cedar Lake, upon which we spent a fortnight, is a pretty sheet of water, the head of a chain of six lakes which open finally into the Fox. It is about a mile in greatest diameter in each direction, with a small but charming island bank near the center, covered with bushes and vines -- a favorite home of birds and wild flowers. The shores vary from rolling to bluffy except for a narrow strip of marsh through which the outlet passes, and the bottoms and margins are gravel, sand, and mud in different parts of its area. Much of the lake is shallow and full of water plants; but the southern part reaches a depth of fifty feet a short distance from the eastern bluff.

Deep Lake, the second of this chain, is of similar character, with a greatest depth of fifty-seven feet -- the deepest sounding we made in these smaller lakes of Illinois. In these two lakes several temperatures were taken with a differential thermometer. In Deep Lake, for example, at fifty-seven feet I found the bottom temperature 53-1/2° -- about that of ordinary well-water -- when the air was 63°; and in Cedar Lake, at forty-eight feet, the bottom was 58° when the air was 61°.

Geneva Lake, Wisconsin, is a clear and beautiful body of water about eight miles long by one and a quarter in greatest width. The banks are all high, rolling, and wooded, except at the eastern end, where its outlet rises. Its deepest water is found in its western third, where it reaches a depth of twenty-three fathoms. I made here, early in November, twelve hauls of the dredge and three of the trawl, aggregating about three miles in length, so distributed in distance and depth as to give a good idea of the invertebrate life of the lake at that season.

And now if you will kindly let this suffice for the background or setting of the picture of lacustrine life which I have undertaken to give you, I will next endeavor -- not to paint in the picture; for that I have not the artistic skill. I will confine myself to the humble and safer task of supplying you the pigments, leaving it to your own constructive imaginations to put them on the canvas.

When one sees acres of the shallower water black with water-fowl, and so clogged with weeds that a boat can scarcely be pushed through the mass; when, lifting a handful of the latter, he finds them covered with shells and alive with small crustaceans; and then, dragging a towing net for a few minutes, finds it lined with myriads of diatoms and other microscopic algae, and with multitudes of Entomostraca, he is likely to infer that these waters are everywhere swarming with life, from top to bottom and from shore to shore. If, however, he will haul a dredge for an hour or so in the deepest water he can find, he will invariably discover an area singularly barren of both plant and animal life, yielding scarcely anything but a small bivalve mollusk, a few low worms, and red larvae of gnats. These inhabit a black, deep, and almost impalpable mud or ooze, too soft and unstable to afford foothold to plants even if the lake is shallow enough to admit a sufficient quantity of light to its bottom to support vegetation. It is doubtless to this character of the bottom that the barrenness of the interior parts of these lakes is due; and this again is caused by the selective influence of gravity upon the mud and detritus washed down by rains. The heaviest and coarsest of this material necessarily settles nearest the margin, and only the finest silt reaches the remotest parts of the lakes, which, filling most slowly, remain, of course, the deepest. This ooze consists very largely, also, of a fine organic debris. The superficial part of it contains scarcely any sand, but has a greasy feel and rubs away, almost to nothing, between the fingers. The largest lakes are not therefore, as a rule, by any means the most prolific of life, but this shades inward rapidly from the shore, and becomes at no great distance almost as simple and scanty as that of a desert.

Among the weeds and lily-pads upon the shallows and around the margin -- the Potamogeton, Myriophyllum, Ceratophyllum, Anacharis, and Chara, and the common Nelumbium, -- among these the fishes chiefly swim or lurk, by far the commonest being the barbaric bream[1] or "pumpkin-seed" of northern Illinois, splendid with its green and scarlet and purple

[1] Lepomis gibbosus.

and orange. Little less abundant is the common perch (Perca lutea) in the larger lakes -- in the largest outnumbering the bream itself. The whole sunfish family, to which the latter belongs, is in fact the dominant group in these lakes. Of the one hundred and thirty-two fishes of Illinois only thirty-seven are found in these waters -- about twenty-eight per cent -- while eight out of our seventeen sunfishes (Centrarchinae) have been taken there. Next, perhaps, one searching the pebbly beaches or scanning the weedy tracts will be struck by the small number of minnows or cyprinoids which catch the eye or come out in the net. Of our thirty-three Illinois cyprinoids, only six occur there -- about eighteen per cent -- and only three of these are common. These are in part replaced by shoals of the beautiful little silversides (Labidesthes sicculus), a spiny-finned fish, bright, slender, active, and voracious -- as well supplied with teeth as a perch, and far better equipped for self-defense than the soft-bodied and toothless cyprinoids. Next we note that of our twelve catfishes (Siluridae) only two have been taken in these lakes -- one the common bullhead (Ictalurus nebulosus), which occurs everywhere, and the other an insignificant stone cat, not as long as one's thumb. The suckers, also, are much less abundant in this region than farther south, the buffalo fishes[1] not appearing at all in our collections. Their family is represented by worthless carp[2] by two red-horse[3], by the chub sucker[4] and the common sucker (Catostomus teres), and by one other species. Even the hickory shad[5] -- an ichthyological weed in the Illinois -- we have not found in these lakes at all. The sheepshead[6], so common here, is also conspicuous there by its absence. The yellow bass[7], not rare in this river, we should not expect in these lakes because it is, rather, a southern species; but why the white bass[8], abundant here, in Lake Michigan, and in the Wisconsin lakes, should be wholly absent from the lakes of the Illinois plateau, I am unable to imagine. If it occurs there at all, it must be rare, as I could neither find nor hear of it.

A characteristic, abundant, and attractive little fish is the log perch (Percina caprodes) -- the largest of the darters, slender, active, barred like a zebra, spending much of its time in chase of Entomostraca among the water plants, or prying curiously about among the stones for minute insect larvae. Six darters in all (Ethcostomatinae), out of the eighteen from the state, are on our list from these lakes. The two black bass[9] are the most popular game fishes -- the large-mouthed species being much the most abundant. The pickerels[10], gar[11], and dogfish[12] are there about as here; but the shovel-fish[13] does not occur.

Of the peculiar fish fauna of Lake Michigan -- the burbot[14], white fish[15], trout[16], lake herring or cisco[17], etc., not one species occurs in these smaller lakes, and all attempts to transfer any of them have failed completely. The cisco is a notable fish of Geneva Lake, Wisconsin, but does not reach Illinois except in Lake Michigan. It is useless to attempt to introduce it, because the deeper areas of the interior lakes are too limited to give it sufficient range of cool water in midsummer.

In short, the fishes of these lakes are substantially those of their region -- excluding the Lake Michigan series (for which the lakes are too small and warm) and those peculiar to creeks and rivers. Possibly the relative scarcity of catfishes (Siluridae) is due to the comparative clearness and cleanness of these waters. I see no good reason why minnows should be so few, unless it be the abundance of pike and Chicago sportsmen.

Concerning the molluscan fauna, I will only say that it is poor in bivalves -- as far as our observations go -- and rich in univalves. Our collections have been but partly determined, but they give us three species of Valvata, seven of Planorbis, four Amnicolas, a Melantho, two Physas, six Limnaeas, and an Ancylus among the Gastropoda, and two Unios, an Anodonta, a Sphaerium, and a Pisidium among the Lamellibranchiates. Pisiduim variabile is by far the most abundant mollusk in the oozy bottom in the deeper parts of the lakes; and crawling over the weeds are multitudes of small Amnicolas and Valvatas.

The entomology of these lakes I can merely touch upon, mentioning only the most important and abundant insect larvae. Hiding under stones and driftwood, well aware, no doubt, what enticing morsels they are to a great variety of fishes, we find a number of species of ephemerid larvae whose specific determination we have not yet attempted. Among the weeds are the usual larvae of dragon-flies -- Agrionina and Libellulina, familiar to every one; swimming in open water the predaceous larvae of Corethra; wriggling through the water or buried in the mud the larvae of Chironomus -- the shallow water species white, and those from the the deeper ooze of the central parts of the lakes blood-red and larger. Among Chara on the sandy bottom are a great number and variety of interesting case-worms -- larvae of Phryganeidae -- most of them inhabiting tubes of a slender conical form made of a viscid secretion exuded from the mouth and strengthened and thickened by grains of sand, fine or coarse. One of these cases, nearly naked, but usually thinly covered with diatoms, is especially worthy of note, as it has been reported nowhere in this country except in our collections, and was indeed recently described from Brazil as new. Its generic name is Lagenopsyche, but its species undertermined. These larvae are also eaten by fishes.

Among the worms we have of course a number of species of leeches and of planarians, -- in the mud minute Anguillulidae, like vinegar eels, and a slender Lumbriculus which makes a tubular mud burrow for itself in the deepest water, and also the curious Nais probiscidea, notable for its capacity of multiplication by transverse division.

The crustacean fauna of these lakes is more varied than any other group. About forty species were noted

[1] Ictiobus bubalus. [2] Ictiobus cyprinus. [3] Moxostoma aureolum and M. macrolepidotum. [4] Erimyzon sucetta. [5] Dorosoma cepedianum. [6] Haploidonotus. [7] Roccus interruptus. [8] Roccus chrysops. [9] Micropterus. [10] Esox. [11] Lepidosteus. [12] Amia. [13] Polyodon. [14] Lota. [15] Coregonus clupeiformis. [16] Salvelinus namaycush. [17] Coregonus artedi.

in all. Crawfishes were not especially abundant, and most belonged to a single species, Cambarus virilis. Two amphipods occurred frequently in our collections; one, less common here but very abundant farther south -- Crangonyx gracilis -- and one, Allorchestes dentata, probably the commonest animal in these waters, crawling and swimming everywhere in myriads among the submerged water-plants. An occasional Gammarus fasciatus was also taken in the dredge. A few isopod Crustacea occur, belonging to Mancasellus tenax -- a species not previously found in the state.

I have reserved for the last the Entomostraca -- minute crustaceans of a surprising number and variety, and of a beauty often truly exquisite. They belong wholly, in our waters, to the three orders, Copedoda, Ostracoda, and Cladocera -- the first two predaceous upon still smaller organisms and upon each other, and the last chiefly vegetarian. Twenty-one species of Cladocera have been recognized in our collections, representing sixteen genera. It is an interesting fact that twelve of these species are found also in the fresh waters of Europe. Five cyprids have been detected, two of them common to Europe, and also an abundant Diaptomus, a variety of a European species. Several Cyclops species were collected which have not yet been determined.

These Entomostraca swarm in microscopic myriads among the weeds along the shore, some swimming freely, and others creeping in the mud or climbing over the leaves of plants. Some prefer the open water, in which they throng locally like shoals of fishes, coming to the surface preferably by night, or on dark days, and sinking to the bottom usually by day to avoid the sunshine. These pelagic forms, as they are called, are often exquisitely transparent, and hence almost invisible in their native element -- a charming device of Nature to protect them against their enemies in the open lake, where there is no chance of shelter or escape. Then with an ingenuity in which one may almost detect the flavor of sarcastic humor, Nature has turned upon these favored children and endowed their most deadly enemies with a like transparency, so that wherever the towing net brings to light a host of these crystalline Cladocera, there it discovers also swimming, invisible, among them, a lovely pair of robbers and beasts of prey -- the delicate Leptodora and the Corethra larva.

These slight, transparent, pelagic forms are much more numerous in Lake Michigan than in any of the smaller lakes, and peculiar forms occur there commonly which are rare in the larger lakes of Illinois and entirely wanting in the smallest. The transparent species are also much more abundant in the isolated smaller lakes than in those more directly connected with the rivers.

The vertical range of the animals of Geneva Lake showed clearly that the barrenness of the interiors of these small bodies of water was not due to the greater depth alone. While there were a few species of crustaceans and case-worms which occurred there abundantly near shore but rarely or not at all at depths greater than four fathoms, and may hence be called littoral species, there was, on the whole, little diminution either in quantity or variety of animal life until about fifteen fathoms had been reached. Dredging at four or five fathoms were nearly or quite as fruitful as any made. On the other hand, the barrenness of the bottom at twenty to twenty-three fathoms was very remarkable. The total product of four hauls of the dredge and one of the trawl at that depth, aggregating fully a mile and a half of continuous dragging, would easily go into a two-dram vial, and represents only nine animal species -- not counting dead shells, and fragments which had probably floated in from shallower waters. The greater part of this little collection was composed of specimens of Lumbriculus and larvae of Chironomus. There were a few Corethra larvae, a single Gammarus, three small leeches, and some sixteen mollusks, all but four of which belonged to Pisidium. The others were two Sphaeriums, a Valvata carinata, and a V. sincera. None of the species taken here are peculiar, but all were of the kinds found in the smaller lakes, and all occurred also in shallower water. It is evident that these interior regions of the lakes must be as destitute of fishes as they are of plants and lower animals.

While none of the deep-water animals of the Great Lakes were found in Geneva Lake, other evidences of zoological affinity were detected. The towing net yielded almost precisely the assemblage of species of Entomostraca found in Lake Michigan, including many specimens of Limnocalanus macrurus Sars; and peculiar long, smooth leeches, common in Lake Michigan but not occurring in the small Illinois lakes, were also found in Geneva. Many Valvata tri-carinata lacked the middle carina, as in Long Lake and other isolated lakes of this region.

Comparing the Daphnias of Lake Michigan with those of Geneva Lake, Wis. (nine miles long and twenty-three fathoms in depth), those of Long Lake, Ill. (one and a half miles long and six fathoms deep), and those of other, still smaller, lakes of that region, and the swamps and smaller ponds as well, we shall be struck by the inferior development of the Entomostraca of the larger bodies of water in numbers, in size and robustness, and in reproductive power. Their smaller numbers and size are doubtless due to the relative scarcity of food. The system of aquatic animal life rests essentially upon the vegetable world, although perhaps less strictly than does the terrestrial system, and in a large and deep lake vegetation is much less abundant than in a narrower and shallower one, not only relatively to the amount of water but also to the area of the bottom. From this deficiency of plant life results a deficiency of food for Entomostraca, whether of algae, of Protozoa, or of higher forms, and hence, of course, a smaller number of the Entomostraca themselves, and these with more slender bodies, suitable for more rapid locomotion and wider range.

The difference of reproductive energy, as shown by the much smaller egg-masses borne by the species of the larger lakes, depends upon the vastly greater destruction to which the paludal Crustacea are subjected. Many of the latter occupy waters liable to be exhausted by drought, with a consequent enormous waste of entomostracan life. The opportunity for reproduction is here greatly limited -- in some situations to early spring alone -- and the chances for destruction of the summer eggs in the dry and often dusty soil are so numerous that only the most prolific species can maintain themselves.

Further, the marshes and shallower lakes are the favorite breeding grounds of fishes, which migrate to them in spawning time if possible, and it is from the Entomostraca found here that most young fishes get their earliest food supplies -- a danger from which the deep-water species are measurably free. Not only is a high reproductive rate rendered unnecessary among the latter by their freedom from many dangers to which the shallow-water species are exposed, but in view of the relatively small amount of food available for them, a high rate of multiplication would be a positive injury, and could result only in wholesale starvation.

All these lakes of Illinois and Wisconsin, together with the much larger Lake Mendota at Madison (in which also I have done much work with dredge, trawl, and seine), differ in one notable particular both from Lake Michigan and from the larger lakes of Europe. In the latter the bottoms in the deeper parts yield a peculiar assemblage of animal forms which range but rarely into the littoral region, while in our inland lakes no such deep water fauna occurs, which the exception of the cisco and the large red Chironomus larva. At Grand Traverse Bay, in Lake Michigan, I found at a depth of one hundred fathoms a very odd fish of the sculpin family (Triglopsis thompsoni Gir.) which, until I collected it, had been known only from the stomachs of fishes; and there also was an abundant crustacean, Mysis -- the "opossum shrimp", as it is sometimes called -- the principal food of these deep lake sculpins. Two remarkable amphipod crustaceans also belong in a peculiar way to this deep water. In the European lakes the same Mysis occurs in the deepest part, with several other forms not represented in our collections, two of these being blind crustaceans related to those which in this country occur in caves and wells.

Comparing the other features of our lake fauna with that of Europe, we find a surprising number of Entomostraca identical; but this is a general phenomenon, as many of the more abundant Cladocera and Copepoda of our small wayside pools are either European species, or differ from them so slightly that it is doubtful if they ought to be called distinct.

It would be quite impossible, within reasonable limits, to go into details respecting the organic relations of the animals of these waters, and I will content myself with two or three illustrations. As one example of the varied and far-reaching relations into which the animals of a lake are brought in the general struggle for life, I take the common black bass. In the dietary of this fish I find, at different ages of the individual, fishes of great variety, representing all the important orders of that class; insects in considerable number, especially the various water-bugs and larvae of day-flies; fresh-water shrimps; and a great multitude of Entomostraca of many species and genera. The fish is therefore directly dependent upon all these classes for its existence. Next, looking to the food of the species which the bass has eaten, and upon which it is therefore indirectly dependent, I find that one kind of the fishes taken feeds upon mud, algae, and Entomostraca, and another upon nearly every animal substance in the water, including mollusks and decomposing organic matter. The insects taken by the bass, themselves take other insects and small Crustacea. The crawfishes are nearly omnivorous, and of the other crustaceans some eat Entomostraca and some algae and Protozoa. At only the second step, therefore, we find our bass brought into dependence upon nearly every class of animals in the water.

And now, if we search for its competitors we shall find these also extremely numerous. In the first place, I have found that all our young fishes except the Catostomidae feed at first almost wholly on Entomostraca, so that the little bass finds himself at the very beginning of his life engaged in a scramble for food with all the other little fishes in the lake. In fact, not only young fishes but a multitude of other animals as well, especially insects and the larger Crustacea, feed upon these Entomostraca, so that the competitors of the bass are not confined to members of its own class. Even mollusks, while they do not directly compete with it do so indirectly, for they appropriate myriads of the microscopic forms upon which the Entomostraca largely depend for food. But the enemies of the bass do not all attack it by appropriating its food supplies, for many devour the little fish itself. A great variety of predaceous fishes, turtles, water-snakes, wading and diving birds, and even bugs of gigantic dimensions destroy it on the slightest opportunity. It is in fact hardly too much to say that fishes which reach maturity are relatively as rare as centenarians among human kind.

As an illustration of the remote and unsuspected rivalries which reveal themselves on a careful study of such a situation, we may take the relations of fishes to the bladderwort[1] -- a flowering plant which fills many acres of the water in the shallow lakes of northern Illinois. Upon the leaves of this species are found little bladders -- several hundred to each plant -- which when closely examined are seen to be tiny traps for the capture of Entomostraca and other minute animals. The plant usually has no roots, but lives entirely upon the animal food obtained through these little bladders. Ten of these sacs which I took at random from a mature plant contained no less than ninety-three animals (more than nine to a bladder), belonging to twenty-eight different species. Seventy-six of these were Entomostraca, and eight others were minute insect larvae. When we estimate the myriads of small insects and Crustacea which these plants must appropriate during a year to their own support, and consider the fact that these are of the kinds most useful as food for young fishes of nearly all descriptions, we must conclude that the bladderworts compete with fishes for food, and tend to keep down their number by diminishing the food resources of the young. The plants even have a certain advantage in this competition, since they are not strictly dependent on Entomostraca, as

[1] Utricularia.

the fishes are, but sometimes take root, developing then but very few leaves and bladders. This probably happens under conditions unfavorable to their support by the other method. These simple instances will suffice to illustrate the intimate way in which the living forms of a lake are united.

Perhaps no phenomenon of life in such a situation is more remarkable than the steady balance of organic nature, which holds each species within the limits of a uniform average number, year after year, although each one is always doing its best to break across boundaries on every side. The reproductive rate is usually enormous and the struggle for existence is correspondingly severe. Every animal within these bounds has its enemies, and Nature seems to have taxed her skill and ingenuity to the utmost to furnish these enemies with contrivances for the destruction of their prey in myriads. For every defensive device with which she has armed an animal, she has invented a still more effective apparatus of destruction and bestowed it upon some foe, thus striving with unending pertinacity to outwit herself; and yet life does not perish in the lake, nor even oscillate to any considerable degree, but on the contrary the little community secluded here is as prosperous as if its state were one of profound and perpetual peace. Although every species has to fight its way inch by inch from the egg to maturity, yet no species is exterminated, but each is maintained at a regular average number which we shall find good reason to believe is the greatest for which there is, year after year, a sufficient supply of food.

I will bring this paper to a close, already too long postponed, by endeavoring to show how this beneficent order is maintained in the midst of a conflict seemingly so lawless.

It is a self-evident proposition that a species can not maintain itself continuously, year after year, unless its birth-rate at least equals its death-rate. If it is preyed upon by another species, it must produce regularly an excess of individuals for destruction, or else it must certainly dwindle and disappear. On the other hand, the dependent species evidently must not appropriate, on an average, any more than the surplus and excess of individuals upon which it preys, for if it does so it will continuously diminish its own food supply, and thus indirectly but surely exterminate itself. The interests of both parties will therefore be best served by an adjustment of their respective rates of multiplication such that the species devoured shall furnish an excess of numbers to supply the wants of the devourer, and that the latter shall confine its appropriations to the excess thus furnished. We thus see that there is really a close community of interest between these two seemingly deadly foes.

And next we note that this common interest is promoted by the process of natural selection; for it is the great office of this process to eliminate the unfit. If two species standing to each other in the relation of hunter and prey are or become badly adjusted in respect to their rates of increase, so that the one preyed upon is kept very far below the normal number which might find food, even if they do not presently obliterate each other the pair are placed at a disadvantage in the battle for life, and must suffer accordingly. Just as certainly as the thrifty business man who lives within his income will finally dispossess his shiftless competitor who can never pay his debts, the well-adjusted aquatic animal will in time crowd out its poorly-adjusted competitors for food and for the various goods of life. Consequently we may believe that in the long run and as a general rule those species which have survived, are those which have reached a fairly close adjustment in this particular.[1]

Two ideas are thus seen to be sufficient to explain the order evolved from this seeming chaos; the first that of a general community of interests among all the classes of organic beings here assembled, and the second that of the beneficent power of natural selection which compels such adjustments of the rates of destruction and of multiplication of the various species as shall best promote this common interest.

Have these facts and ideas, derived from a study of our aquatic microcosm, any general application on a higher plane? We have here an example of the triumphant beneficence of the laws of life applied to conditions seemingly the most unfavorable possible for any mutually helpful adjustment. In this lake, where competitions are fierce and continuous beyond any parallel in the worst periods of human history; where they take hold, not on goods of life merely, but always upon life itself; where mercy and charity and sympathy and magnanimity and all the virtues are utterly unknown; where robbery and murder and the deadly tyranny of strength over weakness are the unvarying rule; where what we call wrong-doing is always triumphant, and what we call goodness would be immediately fatal to its possessor, -- even here, out of these hard conditions, an order has been evolved which is the best conceivable without a total change in the conditions themselves; an equilibrium has been reached and is steadily maintained that actually accomplishes for all the parties involved the greatest good which the circumstances will at all permit. In a system where life is the universal good, but the destruction of life the well-nigh universal occupation, an order has spontaneously arisen which constantly tends to maintain life at the highest limit -- a limit far higher, in fact, with respect to both quality and quantity, than would be possible in the absence of this destructive conflict. Is there not, in this reflection, solid ground for a belief in the final beneficence of the laws of organic nature? If the system of life is such that a harmonious balance of conflicting interests has been reached where every element is either hostile or indifferent to every other, may we not trust much to the outcome where, as in human affairs, the spontaneous adjustments of nature are aided by intelligent effort, by sympathy, and by self-sacrifice?

[1] For a fuller statement of this argument, see Bul. Ill. State Lab. Nat. Hist. Vol. I, No. 3, pages 5 to 10.

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SEWAGE, ALGAE AND FISH*

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Much has been written concerning the effects of stream pollutants on fish life. It is the general belief that fish cannot live in a stream polluted by domestic sewage or industrial wastes. The conservationists would like to have all waste materials prevented from entering out streams, thereby returning them, at least partially, to their virgin state. This, of course, would be ideal, but our population has increased to more than one hundred million people, conditions have changed and the clock cannot be turned backwards. Few people, however, seem to realize that domestic sewage, after proper treatment, increases the stream's biological productivity as represented by the plankton and fish population. It is the purpose of this paper to show that treated domestic sewage acts as a fertilizer for a stream in much the same manner as barnyard manure does for field plants.

While making a biological survey of the Ohio River Watershed the author was able to collect a large amount of data on the relation of domestic sewage to aquatic life. The present paper is based upon the data presented in detail in a supplement of a forthcoming report of the Ohio River Pollution Survey (1).

RELATION OF SEWAGE TO ALGAE

The entrance of untreated domestic sewage produces a well defined series of physical, chemical and biological changes in a flowing stream (2). In heavily polluted streams, the region immediately below the source of pollution is characterized by a high bacterial population. The water frequently has a cloudy appearance, high biochemical oxygen demand and a strong disagreeable odor, all indicating general depletion of dissolved oxygen. Masses of gaseous sludge, rising from the bottom of the more sluggish streams, are often noticed floating near the surface of the water. The plankton population in this region is composed largely of bacteria-eating ciliated protozoa, such as Paramecium and Colpidium. Large numbers of stalked ciliates (Vorticella and Carchesium) are frequently found attached to bottom objects. Colorless flagellates may be abundant, with an occasional chlorophyll-bearing species. The total volume of plankton is usually less than 2000 parts per million, but may reach several times that figure if conditions are optimum for the development of large numbers of protozoa. Long streamers of sewage fungus are frequently attached to submerged objects. The fishes that normally penetrate this region are carp and buffalo and they are found near the sewer outlet, feeding upon the raw sewage, where the bacterial action has not yet depleted the dissolved oxygen. These fish survive the prevailing low oxygen concentration by coming to the surface to "gulp" air.

Farther down stream, after sufficient time has elapsed for the masses of bacteria to decompose the sewage, the water tends to become clear and the dissolved oxygen level is sufficiently high to support forage and rough fish. The plankton population is slightly higher than upstream but is still composed largely of ciliated protozoa and colorless flagellates. Chlorophyll-bearing species are beginning to make their appearance in noticeable numbers. Blue-green and filamentous green algae are commonly found along the margins and bottom of the stream. Accumulated oxygen may bring large masses of the bottom algae to the surface of the water and give to the stream an unsightly appearance. (These floating islands of algae should not be confused with the gaseous sludge masses previously mentioned.) The combined photosynthetic action of all the green plants is an important factor in raising the oxygen level, especially on bright sunny days.

The adjacent region farther downstream clearly shows the beneficial effect of the decomposed sewage which entered upstream. The bacterial action in the upper reaches of the stream has oxidized the complex organic compounds present in the sewage to nitrates and phosphates. The availability of these end products as plant foods results in the development of large numbers of chlorophyll-bearing algae, which furnish food for the zooplankton and this food supply results in an increase in the population of mixed fishes (Fig. 1). The photosynthetic action of the green algae in this region increases the dissolved oxygen, often to supersaturation during the day, which, however, decreases at night but seldom to the asphyxial level for fishes.

Still farther downstream the plankton population drops sharply, probably owing largely to the utilization of the available food materials by the heavy growth of plankton in the upstream region. There is a tendency for a reduction in the forage and rough fishes, but the game fishes tend to increase.

The above statements give a brief description of the conditions present in a small stream that receives untreated domestic sewage. However, if the waste

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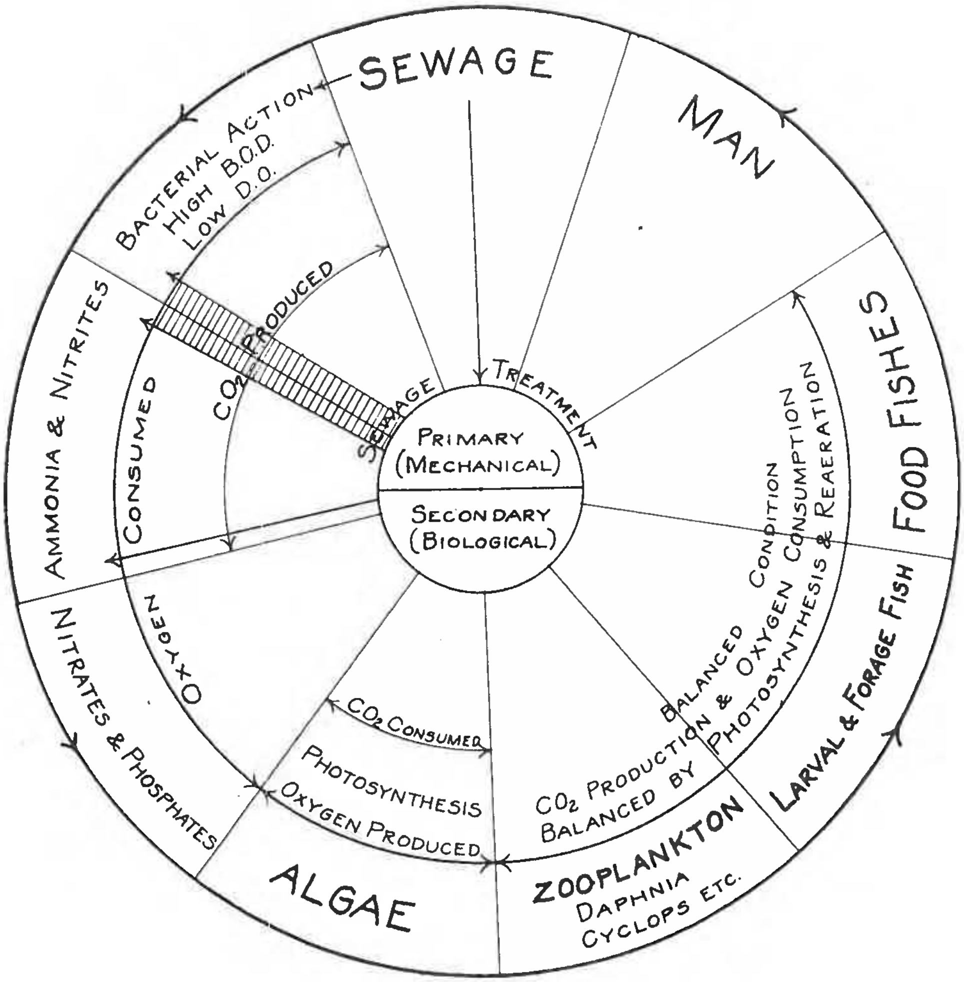

FOOD CYCLE

Figure 1 - Food Cycle in a Polluted Stream. Sewage or other putrescible organic matter after entrance into a flowing stream is changed by bacterial action into ammonia and nitrites and finally into nitrates and phosphates. These latter compounds are assimilated by the algae and result in an increase in growth of these plants. The algae are consumed as food by the larger plankton, zooplankton, which in turn are eaten by fishes. Cross hatched area shows the condition of the effluent as it leaves the treatment plant. The effluent from a primary plant contains some ammonia and nitrites, but is still subject to bacterial action after disposition into the receiving stream. The degradation zone, of high bacterial action, high B.O.D. and low D.O., in the stream can be eliminated by passing the sewage through a complete or secondary treatment plant. Complete treatment converts much of the organic matter into nitrates and phosphates which become immediately available for plant growth resulting in an increased fish population.

receives complete or secondary treatment, so that the bacterial action oxidizes the sewage to available plant foods before the effluent enters the stream, the early obnoxious stage will not occur and the stream will be benefited by the fertilizing effect of the sewage for many miles of its length. Beneficial effects of primary treatment are shown by the reduction in sludge deposits and a shortening of the zone of degradation.

RELATION OF SEWAGE TO FISH LIFE

The effect of sewage on fish life varies with the season and also with the time of day. In summer the fish are active, their metabolic rate is high and more oxygen is required for their respiration than during the winter, when their activity is greatly reduced. On the other hand, during the warm summer periods the bacterial decomposition in a heavily polluted region of a stream is at its maximum, resulting in an increased biological oxygen demand and a lower dissolved oxygen concentration. The solubility of oxygen, moreover, is less in warm water than in cold water, so that less oxygen is absorbed from the atmosphere and held in solution. The increased oxygen requirement of the fish and the reduced oxygen concentration of the water renders hot weather particularly unfavorable for fish life in a polluted stream. Fish, therefore, usually die of suffocation during warm periods in regions grossly polluted by putrescible organic matter. It must not be assumed that summer is the only time that fish suffer from low oxygen concentration, because thousands of fish may die under ice by suffocation owing to the depletion of oxygen by decaying organic matter. This condition may last for only a day or two but that is sufficient time to destroy the fish population in a stream.

The toxicity of the hydrogen sulfide and other compounds produced by anaerobic bacterial action in the bottom sludge deposits may be an important factor in the death of fishes in streams receiving untreated sewage. Ellis (3) reports that 10 p.p.m. of H_2S in hard water killed goldfish in 96 hours or less. Local freshets resulting from heavy rains during low water periods tend to mix the sludge with the supernatant water and to carry the putrid mass downstream. The resulting reduction in the dissolved oxygen and the end products of anaerobic bacterial action destroy the fish for miles below.

It is also well known that heavy organic pollution causes an increase in disease, parasitism and abnormalities among fishes.

The deposition of sludge on the bottom of streams renders that portion of the stream unfit for nesting sites and will smother any eggs that may have been laid prior to the entrance of the waste. Polluted regions may act as barriers to the upstream migration of fish for the purpose of spawning.

RELATION OF ALGAE TO FISH LIFE

Algae serve directly or indirectly as food for all fishes. The green algae are the medium by which the complex organic compounds in sewage, following bacterial decomposition, are transferred to fish. The organic compounds, as previously stated, are converted by bacterial action into available plant foods. These materials are absorbed from the water by the aquatic plants and by the process of photosynthesis, and other cellular activities are converted into the living plant cell. The organic materials comprising the green algae are transferred to the fish through the medium of the zooplankton which are found associated with the algae. Small fish feed directly upon the algae and zooplankton and the adults of many species, such as the shad, live almost entirely upon the microscopic life in the water. The larger zooplankton such as Daphnia, Cyclops, etc., are important articles of diet for larval and small species of fish; in turn, these are eaten by larger fishes which may become the food of man (Fig. 1).

As stated in the first section of this paper, domestic sewage, after it has been decomposed by bacterial action, either in the stream or previously by artificial secondary treatment, increases the growth of aquatic plants by virtue of the fertilizing value of the end products. These plants furnish food for the zooplankton which in turn furnishes food for fish and thus the fish population is increased in regions where stream fertilization by sewage occurs.

Another important factor in the relation of algae to fish life is the reoxygenation of the stream by the photosynthesis of algae. The combined photosynthetic action of all the algae may increase the dissolved oxygen to supersaturation during sunny days. Purdy (4) has shown that Oocystis increases appreciably the amount of oxygen in a closed sample of water. The fact must not be overlooked, however, that the plants themselves, in addition to all forms of aquatic life, consume oxygen during the process of respiration, so the rapid rise of oxygen during the day may be followed by a disastrous fall in the early morning hours if the stream is heavily polluted by decaying organic matter.

Photosynthesis also removes from the water carbon dioxide which is produced as a waste product by the living cell and the decomposition of organic matter. Wells (5) has shown that fishes are very sensitive to small changes in the carbon dioxide content of the water and tend to avoid detrimental concentrations of this gas by moving away to more favorable locations when possible, and that fresh water species of fish tend to select regions where the CO_2 concentration lies between 1 and 6 cc. per liter.

Turbidity may occur in hard-water ponds by the removal of the CO_2 by plants with the subsequent precipitation of the carbonates that are held in solution by the carbonic acid in the water. The removal of CO_2 tends to keep the water from becoming acid, but fish will tolerate without apparent harm a pH as low as 4.5 (6).

SUMMARY

Data obtained from a pollution survey of the Ohio River Basin clearly show that the decomposition products of domestic sewage and other putrescible organic matter increase the growth of plankton, which growth is reflected in an increase in the fish population.

Untreated or raw sewage, when in sufficient concentration, produces a toxic area below the sewer outlet. The region extends downstream for a variable distance, until the sewage is decomposed by bacteria. From this point, the stream is benefited by the fertilizing action of the decomposition products.

When the sewage has received proper secondary treatment, the toxic or degradation zone does not exist and the entire stream will be benefited biologically by the available plant foods introduced.

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BIOLOGICAL ASPECTS OF STREAM POLLUTION*

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The entry of pollutants into a flowing stream sets off a progressive series of physical, chemical and biological events in the downstream waters. Their nature is governed by the character and quantity of the polluting substance. Domestic or industrial effluents may adversely affect natural stream life by direct toxic action or indirectly through quantitative alterations in the character of the water or the stream bed. These facts imply that the presence of polluting substances produces physical, chemical and biological changes that may be recognized as dependable criteria of stream conditions.

The value of physical and chemical data is recognized generally by those concerned with stream pollution and its control. Methods used in gathering these data are fairly well standardized and practiced. Biological procedures have not, as yet, attained an equal degree of refinement. In some ways this is surprising, for the complex interactions resulting from stream pollution are predominantly biological. The determinations of biochemical oxygen demand and dissolved oxygen are essentially for the purpose of finding out how much bacterial food is available and how the bacteria like their diet. Other applications of these data are well known.

The biological phase of stream sanitation is still an infant science, with many of its procedures, refinements and applications still to be worked out. For this reason the following discussion is of a general nature and refers primarily to stream pollution resulting from the introduction of raw or partly treated sewage. Industrial or toxic types of wastes are not considered. Personal field observations and the publications of others have been drawn upon freely for interpretation.

Biological aspects of stream pollution will be considered in a general way from two separate but related points of view: (1) how pollutants change the character of the stream as a habitat for organisms, and (2) the action of organisms upon the pollutant and their related distribution.

The fundamentals of stream biology may best be illustrated by reference to a fictional stream whose hypothetical character may be molded with a free hand. This stream has a semi-solid bottom, medium gradient, average width of about 75 feet, and depth of 6 feet. It flows through alternating wooded and cultivated areas. It is blessed, for our purpose, by having a single source of man-made pollution -- the community of Windmill. Sewage is discharged directly to the stream.

The stream water reaching this community is not pure, for the word, as commonly used, is only relative. Drainage from the land already has added humus extracts, organic particulate matter and inorganic salts leached from the soil. Drainage from cultivated land is rich in the elements that stimulate plant growth,

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and pasture lands contribute organic wastes and intestinal bacteria. These contributions are sometimes called "natural pollution." Whether the origin is natural or from a sewer outlet, the stimulatory effect upon organisms is the same in principle. The recognizable result is that the unpolluted stream supports a variety of organisms as a normal biota.

EFFECTS OF POLLUTION ON BIOLOGICAL ENVIRONMENT

The entry of pollutants changes in many ways the conditions under which stream organisms normally live. This discussion can consider only a few, but there are changes in the stream bottom, in the physical and chemical properties of the water and in the competitive relations of organisms.

Sewage is a complex mixture of many kinds of substances that have been discarded by man because, to him, they have no further value. The constituents are organic and inorganic, simple compounds and complex ones. The organic substances include carbohydrates, proteins and fats as well as their decomposition products. There are salts of various kinds including ammonium salts, nitrates and nitrites. Organic growth stimulators also are a part. Some of the sewage substances are in solution, some colloidal and others suspended but capable of settling. It follows, then, that a recipient stream will have its waters affected by all fractions of the sewage while the stream bed is altered primarily by settling particulate matter.

If the stream is represented graphically (Figure 1) with mileage distances (or hours of flow) on the horizontal axis, the fictional community of Windmill is located at the zero level. Distances upstream are to the left and downstream to the right. The intensity of varying environmental conditions is plotted along the vertical axis. Food for organisms -- chemists call this B.O.D. -- is shown as curve F. The introduction of sewage tremendously augments the normal supply and thus alters this environmental factor. As the food supply is increased by pollution, the bacterial population tends to increase in geometric proportion and draws upon the available food (Figure 4). It is to be expected that the food supply will decline downstream and will eventually approach the pre-pollutional value. This is found to be a fact.

All organisms require oxygen for the maintenance of life. When applied to food, it functions in releasing the life-supporting energy that foods contain. Man draws upon the atmospheric supply by breathing, while most aquatic organisms draw upon the oxygen dissolved in water. Bacterial reduction of the pollutional food supply -- desirable and necessary as it may be -- is not accomplished without cost. That cost is reduction in dissolved oxygen concentration beyond the point required by desirable water animals.

The normal oxygen value of clean water is shown as areas A, from this level to 40 per cent of saturation as B, lesser concentrations as C, and those increasing beyond 40 per cent of saturation as D. These areas also mark the arbitrary limits of stream zones based upon oxygen concentration. The descriptive names are <u>clean water</u> for <u>A</u>, <u>degradation</u> for <u>B</u>, <u>active decomposition</u> for <u>C</u> and <u>recovery</u> for <u>D</u>.

If the pollutional load is fairly light or the dilution factor high, the sag curve resembles the upper curved line with normal value reestablished at 58 miles. This is accomplished by addition of oxygen from the atmosphere and through the activity of green plants. Where the content of organic matter is sufficiently high, dissolved oxygen may be reduced to zero through the oxygen-absorbing efficiency of bacteria. This is the ultimate in organic stream pollution and the circumstance upon which the following discussion is based. This poorest of stream conditions will be discussed since conditions that are less severe are then readily apparent also.

Ten miles below Windmill is the beginning of a 20-mile zone in which dissolved oxygen is absent entirely.

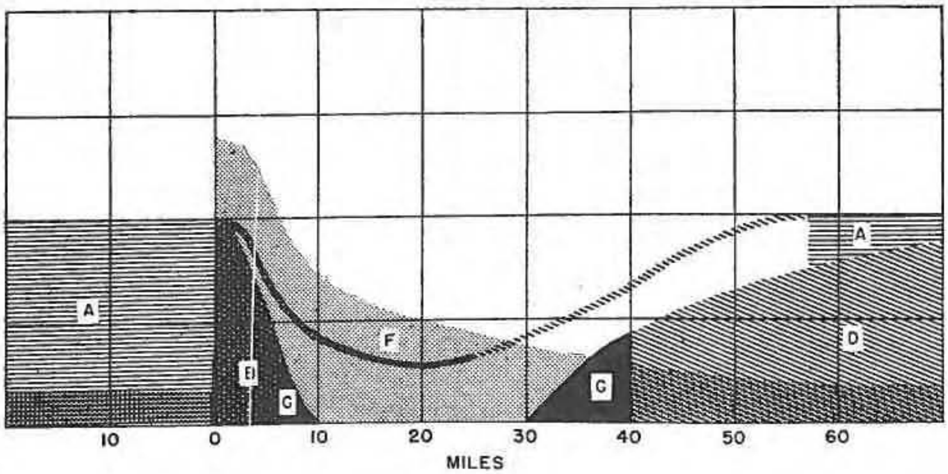

Figure 1 - Graphic representation of hypothetical polluted stream showing relationship of biotic food supply (F) and dissolved oxygen sag curve.

Here, the biotic demand for oxygen is greater than the supply provided by solution from the atmosphere. Bacteria and certain other organisms occupying this septic region are obliged to obtain the required oxygen from other sources. This they do by reducing oxygen-bearing compounds by anaerobic processes. Such activity may result in depleting the supply of oxygen found chemically in nitrates and nitrites, and reduces sulfates to hydrogen sulfide with its offensive odor and toxic action. These are some of the causes for rising gas bubbles and sludge in the septic zone. The gases alone make living conditions here unattractive for most forms of life.

Stream environment is further affected by the suspended semi-solids of sewage (Figure 2-A). These affect green free-floating stream life by immediately decreasing the transparency of the water and blotting out the sunlight. Downstream from the sewer outlet the water is turbid and slightly brownish, becoming dark and murky in the septic zone. As oxygen is added downstream by reaeration, the water gradually clears and finally is tinged with green by suspended microscopic plants.

Organisms that live in the stream bed are also affected by the suspended matters of sewage. These finally settle to the bottom (Figure 2-C) as a blanket of debris that effectively covers the normal habitat of clean water bottom life. It is an inexhaustible source of food but will sustain only those organisms that can qualify for life in that habitat. They must be efficient in obtaining oxygen, for conditions frequently are anaerobic. They must be able to burrow and creep so as to stay on top of the steadily growing layer, or else must be indifferent to being covered over. They must resist the toxic action of hydrogen sulfide and other gases that may emanate continuously from the deeper sludge layers.

Thus, it is seen that sewage alters the normal conditions of food supply, dissolved oxygen, turbidity, bottom surface, and chemical character of the stream and its bed. These are but a few of the environmental alterations that result from sewage pollution. They are sufficient to show that biological changes are sure to follow. Alteration in the competitive relations of stream life will be shown in subsequent discussion.

ACTION OF ORGANISMS UPON THE POLLUTANT AND THEIR RELATED DISTRIBUTION

It is apparent that most modern methods for the treatment of sewage depend, at some stage or another, upon the activities of living organisms. So much is this the case that all sorts of schemes have been devised for pampering the biotic associations and fostering their work. Biological competition is removed in the wastage of activated sludge, and oxygen is supplied to excess. The trickling filter brings the organisms food and oxygen and washes away their metabolic wastes and products. In the sludge digester, they are kept warm so their work proceeds properly and at a rapid pace. In the final analysis, the modern treatment plant is an artificial, telescoped, polluted stream with the zone of degradation at the primary tank and the recovery zone in the final effluent. The high efficiencies obtained are related entirely to these artificial stimulatory conditions, for the fundamental biological processes are the same as in the less efficient stream.

It has been shown that sewage is food, stimulation and habitat for simple forms of life, and that reduction in the organic stream load is accompanied by a corresponding extraction of oxygen. It is not the intent of this discussion, nor within the ability of the writer, to give in detail the precise bacterial activities involved in this accomplishment. At the same time, the basic information is important and needs consideration.

The millions of bacteria in sewage-laden waters are of a variety of kinds and have a variety of abilities. Some of these are normal inhabitants of both clean and

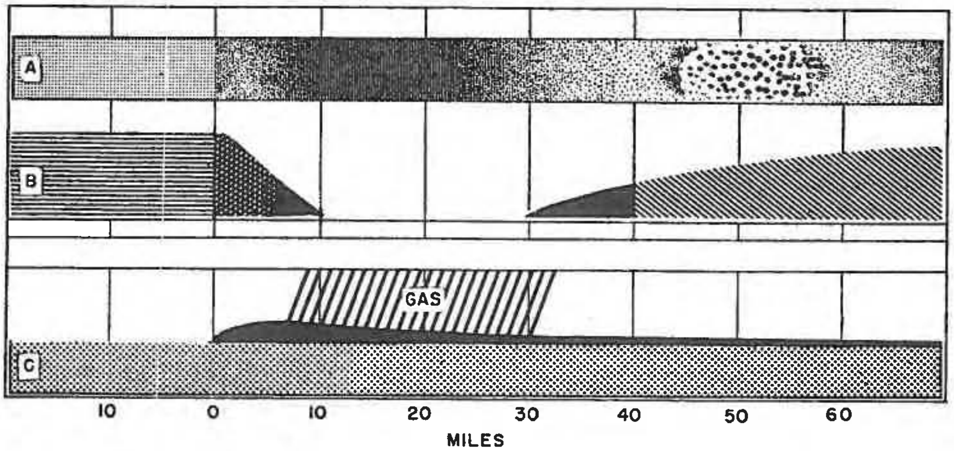

Figure 2 - Biotic habitat alterations resulting from stream pollution. (A) Physical changes in water resulting from entry of raw sewage at zero mileage level; (B) dissolved oxygen sag curve; and (C) accumulation of bottom sludge deposits and rising gas bubbles.

foul water. The presence of sewage stimulates their population increase (Figure 4). Others find their way into the stream in tremendous numbers as normal inhabitants of sewage. Some bacteria are able to multiply in the stream, while others such as B. coli and disease producers appear to die off gradually downstream. They may starve to death, be eaten by predators, be killed by high acidity, or disappear in still other unknown ways. In any event, the population peak is in the near downstream vicinity of the pollutional source.

Some bacteria can act upon a given organic compound, derive energy and growth material from it, and leave an altered residue that serves a different bacterial species or other organism in the same manner. In this way, chains of progressive actions are set in motion that result eventually in the transformation of sewage to simpler, innocuous substances. Some of these are carbon dioxide and water from carbohydrates and fats, and salts of phosphorus, sulfur and nitrogen from protein. Evidence of this mineralizing process is found in the progressive quantity shift from organic nitrogen, to ammonia, to nitrites and finally to nitrates as the water proceeds downstream.

As bacteria grow and multiply, selected constituents of the sewage are incorporated into their living substance. The ability to do this distinguishes all nonliving from living matter. It is an important ability, for in its practice a part of the sewage is set aside momentarily for action at a later time. On this account, bacteria sometimes are called concentrators of the pollutional load.

These activities of bacteria proceed in all parts of the stream. They are distributed throughout the water and are mixed into and over the bottom deposits. Under conditions of intense pollution, dissolved oxygen eventually is depleted in the flowing stream. Such depletion is more frequent and widespread in the bottom sludge. When this condition prevails, as from the 10 to 30-mile levels in the illustrative stream, bacterial action becomes of a different sort. In this septic region bacteria that are able to do so, act upon oxygen-bearing compounds in such a manner that oxygen from outside sources is not required. These bacteria are commonly called anaerobes. Their actions are to be prevented, if possible, for their products are various acids and such gases as ammonia, methane and hydrogen sulfide. Living conditions here are suitable only for organisms unaffected by these products and indifferent to oxygen supply.

Biological action in the stream continually decreases the food supply so that at 50 to 60 miles the concentration approximates the upstream values. Bacteria decrease in much the same pattern so that normal populations are attained at about the same level.

In addition to bacteria, unpolluted streams support a variety of other kinds of organisms. Those forms that produce their required food from minerals, carbon dioxide and water are members of the plant kingdom. Animals are those that require a supply of food already prepared. Bacteria and molds resemble animals in their food habits, but are classed as plants that lack the ability to make food. Organisms may be classified further by their position in the stream. Those that are small, suspended in the water and swept along with the current, are called the plankton. Plankters may be either plant or animal. Organisms that are attached to, lie upon, creep over or burrow into the stream bed are called the benthos. As has been stated, the bacteria occupy all of these positions. Large animals such as fish, frogs and turtles are not considered in this classification scheme.

Clean waters support a wide variety of organisms consisting of plant and animal plankton as well as benthic organisms. They are exacting in their habitat requirements and are affected by any interfering alterations. Normal changes in temperature, light, dissolved oxygen and food supply tend to result in shifts in the population picture. These, however, are rarely great, for predation, death and growth moderate the changing tendency and keep the biotic society in balance. In this society are organisms ordinarily associated with clean stream conditions. Some of these are game fishes such as trout, bass, blue-gills and pike, and smaller animals such as mussels, crayfish, snails and the larvae of caddisflys, stoneflies and dragon and damselflies. Shrimplike scuds may be present, swimming about on their sides or climbing over vegetation. A complete list of these organisms would be a long one.

In such a list of inhabitants would be the names of some organisms that are just holding their own, never building an appreciable population. Competition is too keen, food supply too low, and the habitat not quite suitable. Some of these would fare better in the polluted portions of the stream.

SIGNIFICANCE OF BIOLOGICAL POPULATION

The remainder of this discussion is based upon the principle that organisms differ, not only in appearance, but also in their power of response to conditions of the environment. If all moderating factors for a given organism are removed, the organism will thrive and produce tremendous numbers. On the other hand, if environmental factors are inhibitory, numbers will be small or totally absent. A set of conditions that are ideal for one organism may be lethal for another.

If changing conditions, such as pollution, are unfavorable, organisms must resist these changes, migrate or be destroyed. But, if conditions are favorable for certain organisms, these will thrive and build high populations. For this reason, the society of organisms found in zones of pollution is highly significant. It offers clues to the intensity of pollution and the degree of recovery.

Let it be supposed that the clean waters of the illustrative stream will provide suitable living quarters for a hundred different kinds of organisms, -- a balanced society of plant and animal species (Figure 3-A). With the entry of sewage, the variety decreases rapidly. Of these 100 species upstream the majority find conditions for life unsuitable in the zones of pollution. It is only downstream in the recovery zone where biotic variety makes a gain.

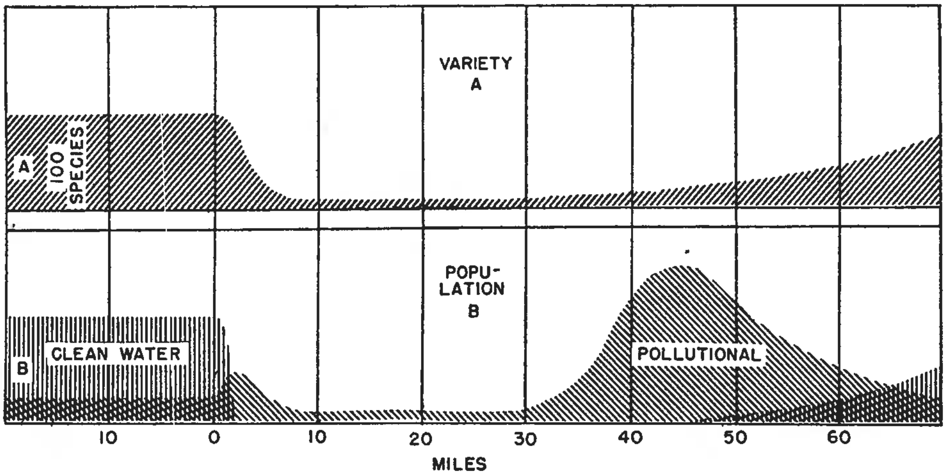

Figure 3 - Responses of bottom organisms to entry of raw sewage at zero mileage level. (A) Varity distribution; (B) population alterations of "clean water" and "pollutional" bottom forms.

Strange as it may seem, these few species in the pollutional zones find conditions quite suitable. Here they thrive in the absence of competition and with a high food supply. They are the ones that are intimately concerned with stream recovery. They may be called pollutional organisms.

If the biotic population be differentiated into clean water and pollutional organisms (Figure 3-B), their distribution may be contrasted. Bacteria are excluded from this graph. Clean water population drops abruptly to zero with the introduction of sewage. The population increases downstream with the variety increase. Pollutional population is low in clean water, but response is quick in the presence of wastes. Even these organisms decline in the true septic zone where only the anaerobes can live. The population peak will occur near the 45-mile level where food is abundant and oxygen again sufficient for the biotic needs. In the absence of a septic zone, both population peaks would roughly coincide. This condition will apply also in the following graphs. Population drop from the 45-mile point reflects approaching exhaustion of the food supply.

POLLUTIONAL ORGANISMS AND THEIR FUNCTIONS

Swimming about among the bacteria and creeping over the bottom sludge are minute animals composed of a single structural unit or cell. Some of these are able to utilize complex dissolved and particulate organic substances and in this way parallel the action of bacteria. Their prime function, however, is a more important one. They drive the bacteria and keep them at work. This is accomplished by the simple expedient of voraciously eating the bacteria so that they must reproduce to maintain their numbers. Since growth is a prelude to reproduction, biochemical oxidation proceeds at a feverish pace.

The bacteria-eaters are mainly those protozoans equipped with cilia which they use for swimming and food gathering. They move about continuously, lashing the water with their cilia and setting up currents that sweep bacteria into the gullet. This practice is carried out wherever bacteria occur. Following due process of ciliate digestion, the bacterial substance is now protozoan substance. The presence of bacteria and organic supplies results in a population peak below the bacterial peak as well as one above the septic zone (Figure 4).

But, for these protozoans all is not sublime -- they too have enemies. As they are swept downstream or flutter over the mud, they finally fall victim to rotifers, water fleas and related crustaceans that select them for variety in their diet of bacteria and small algae. The peak crustacean population is at the 58-mile point (Figure 4). And so it goes, the larger eating the smaller until the food progression leads to mussels, crayfish, small fish and large fish.

Mainly restricted to the bottom is another array of biotic forms. These are perhaps the most dependable indicators of stream condition. Ordinarily, the pollutional bottom is a confusion of biological activity -- each member of the assemblage going about his own business of gathering food and reproducing. To them, stream recovery is merely incidental. The distribution of species is governed by the stringency of habitat conditions.

Rat-tail maggots (Figure 5-A) are a sign of extremely poor conditions. Thus ugly larva of the drone-fly (Eristalis tenax) lies buried in the mud with the tail extended to the surface for air. For this reason, dissolved oxygen is not a consideration and it may penetrate into the septic zone.

Next in line come the sludge-worms (Tubificidae) (Figure 5-B), reddish in color, 1/2 inch to 1-1/2 inch

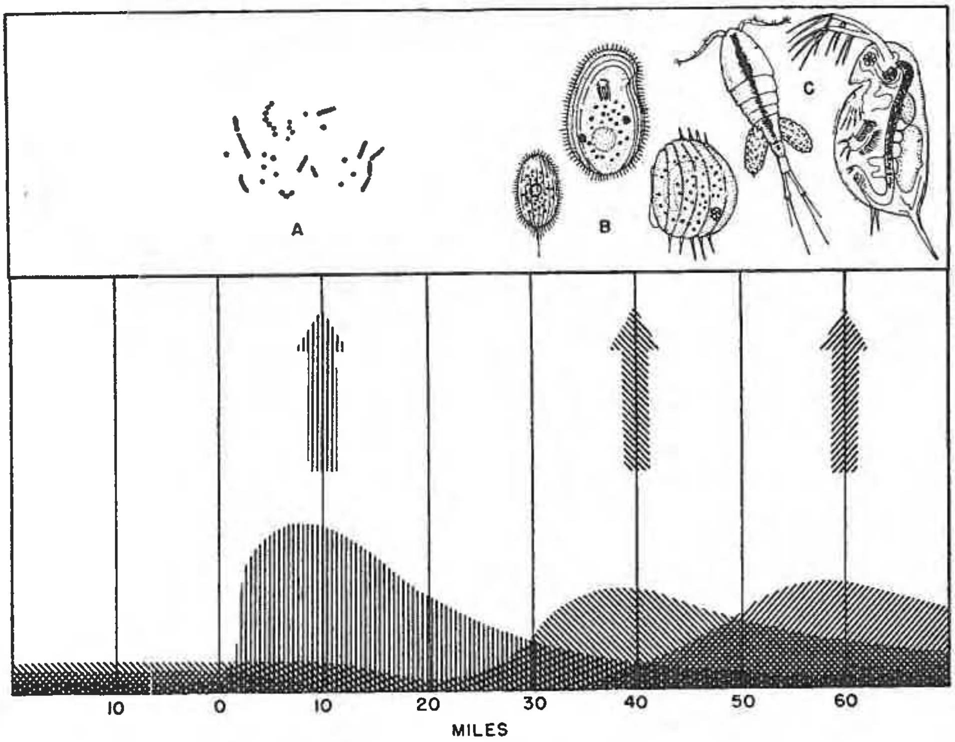

Figure 4 - Linear alterations in populations of bacteria, ciliate protozoans, and crustaceans.

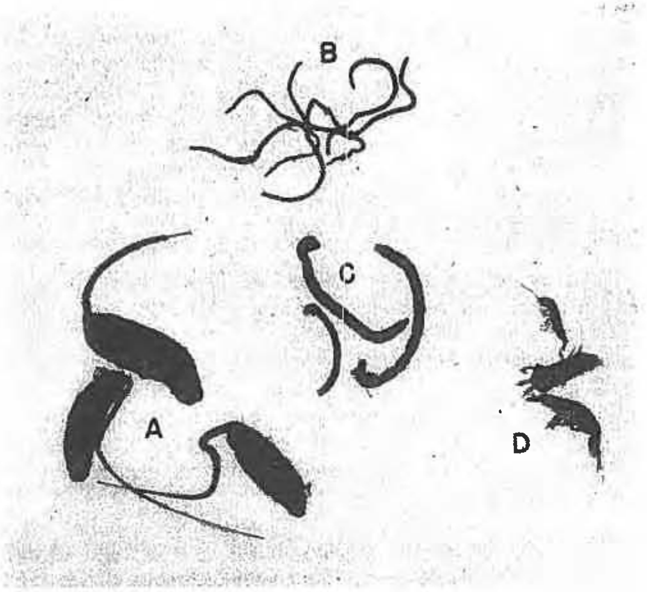

Figure 5 - Bottom organisms found in zones of pollution. (A) Rat-tail maggot (Eristalis tenax); (B) Sludge-worm (Tubifex sp.); (C) Blood-worm (Chironomus sp.); and (D) Sow-bug (Asellus communis). Approximately natural size.

in length. They burrow in the mud where organic content is high. They excavate in the upper layers of the sludge, passing large quantities through the intestinal tract and straining out the food. With the posterior part of the body projecting into the water, the worms cast rejected parts of the sludge on the surface in the form of fecal pellets. The work accomplished in this manner is tremendous. The sludge is worked over, perforated and its organic content reduced.

Frequently these worms are so numerous that the stream bed appears as a red undulating sheet. They occupy the zones of degradation, active decomposition and the upper part of the recovery zone. They are absent from the septic region.

Blood-worms (Chironomus sp.) also are burrowers in the mud. These are red, jointed, worm-like animals (Figure 5-C) that eventually transform to midge-flies. In this larval stage, they occupy burrow-like tubes constructed of sludge stuck together with an adhesive substance. Empty tubes are common and may occur in heaps. Their food habits are similar to the sludge worms, but they are more exacting in their habitat requirements. For this reason they reach their peak in the recovery zone.

At this point, also, the sow-bug or water-log-louse (Asellus communis) makes its first appearance. They are flattened, greyish animals about 1/4 inch long

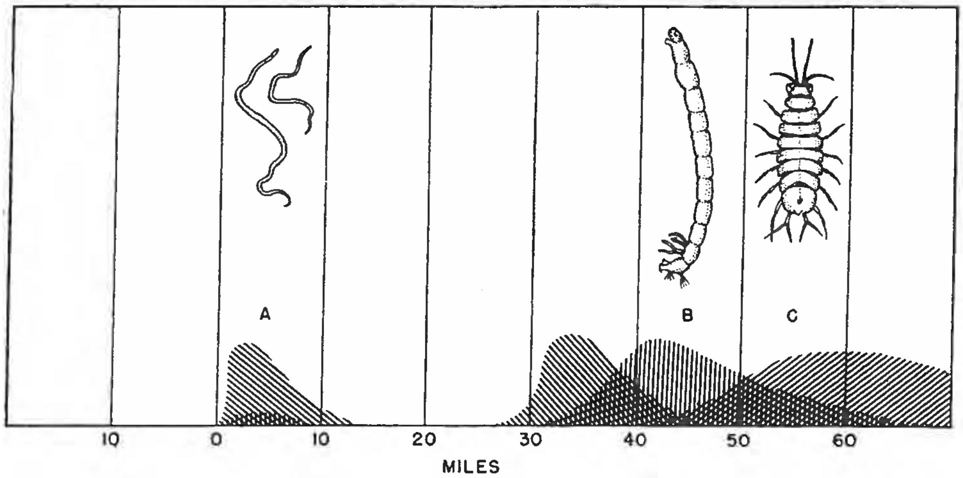

Figure 6 - Linear alterations in populations of sludge-worms (A), blood-worms (B), and sow-bugs (C).

(Figure 5-D), related to the scuds found in clean water. They are provided with jointed appendages, of which six pairs are modified as legs. They crawl about on the bottom, under stones, or climb among water weeds. They do not move by swimming.

Sow-bugs are omnivorous in their feeding habits but seem to prefer dead and decaying vegetable matter. Their oxygen requirements apparently are greater than those of sludge-worms or blood-worms. They are common in the recovery zone where dissolved oxygen in the supernatant water exceeds 40 per cent of saturation. They indicate improving conditions.

If the distribution of sludge-worms, blood-worms and sow-bugs are plotted together, their population peaks occur in the succession shown in Figure 6.

In addition to bacteria, other plants also are involved in stream recovery. Sewage molds and filamentous bacteria may be seen attached to sticks, stones and vegetation, waving gracefully in the current (Figure 7). They function with the bacteria in biochemical oxidation. They are whitish gray, becoming tinged with yellow, red or brown when old. In the zone of degradation, growth is widespread and luxuriant. It persists to the septic region and reappears feebly with

Figure 7 - Sewage mold (Sphaerotilus natans) attached to sticks, stones and vegetation and waving in the current.

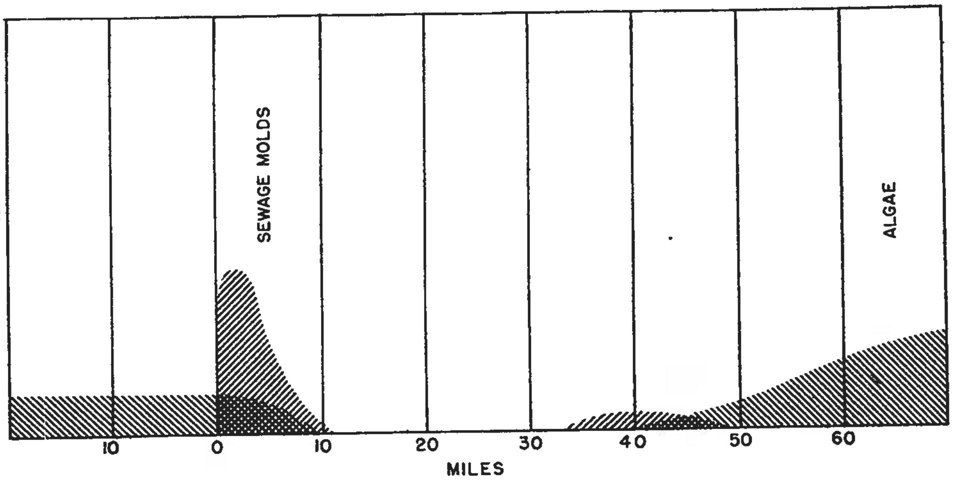

Figure 8 - Linear alterations in populations of sewage molds and plankton algae.

oxygen restoration. Its presence is a reliable index of intense pollution -- especially by carbohydrates.

The distribution of plankton algae, as a group, is in contrast to the sewage molds (Figure 8). The clean water population is reduced rapidly in the degradation zone where turbidity is high. They may be very sparse or absent throughout the septic region and then increase to a new high under the stimulatory influence of phosphorous and nitrogen compounds oxidized from sewage sources.

In the pollutional zones benthic algae may occur as a dark film over the bottom or as a bright green scum along the banks and in quiet spots. Most of these are filamentous, although some may be single-celled and able to swim. Some, at least, absorb certain organic solutions from the water. Valuable as this may be, the algae are more valuable for the oxygen they add to the water in the process of making food. They are instrumental in drawing up the lower end of the sag curve. They supply oxygen for the biochemical demand and speed the recovery process.

SUMMARY

Living organisms are affected by the conditions of stream pollution. Their distribution is altered and may be used to complete the pollutional picture obtained by the usual testing procedures. Their activities contribute tremendously to stream recovery by using pollutants as a source of energy and growth material. Some eat bacteria and thus accelerate their biochemical activities. Green organisms supply oxygen so greatly needed for B.O.D. satisfaction and sag curve elevation. Metabolic wastes, products and dead bodies are passed back to the stream as an altered link of a continuous chain. Biological efficiency in the stream falls far short of that in the treatment plant. A good treatment plant at Windmill would confine these activities and restore utility to the running stream.

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SOME IMPORTANT BIOLOGICAL EFFECTS OF POLLUTION OFTEN DISREGARDED IN STREAM SURVEYS

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The complexity of the pollution problem is being constantly intensified by the ever-increasing variety of pollutants that are added to streams. Due to the fact that pollutants, domestic and industrial, represent only a portion of the many factors which determine stream environments, the same pollutant may not bring about similar conditions in different streams. The character of the watershed, including soil type, amount and type of ground cover, and land uses; the amount, seasonal distribution, and type of precipitation; the frequency of floods and the amount of erosion; and the character of the stream banks, bottom materials, gradient and stream flow are all of importance. These and other factors determine stream characteristics, environmental conditions, the aquatic biota, and in large part the effects of different polluting substances.

SOME BIOLOGICAL EFFECTS OF POLLUTANTS

Pollutants may alter the stream environments and thereby affect aquatic life in a number of ways. These environmental changes may include an increase in stream temperatures; changes in the character of the stream bottom; increase in turbidity; changes in the content of dissolved oxygen; increase in dissolved nutrients; production of undesirable growths; deposition of sludge beds; and the addition of toxic wastes. The degree or extent of the effect of these changes on aquatic life varies with the type and amount of the pollutant and the character of the receiving water. It is the purpose of this paper, therefore, to point out some of the possible effects of pollution on aquatic life and to indicate pertinent ecological conditions which should be noted in stream surveys.

Water used for cooling purposes in industrial processes may become so hot and be of such quantity that it may substantially raise the temperature of the receiving stream. The addition of a waste or wash water having a fairly constant temperature tends to stabilize stream temperatures, especially during the winter (31) and may increase productivity through increased metabolic activity. Moderate heating by increasing metabolism can hasten the natural purification process and shorten the pollutional zones (56). In trout streams even a slight rise in temperature is usually undesirable (6). Due to the removal of shade and other factors (73) (64), many trout streams are approaching borderline temperatures (87) and a rise of even two to three degrees Fahrenheit sometimes is sufficient to eliminate trout or to make the stream less favorable for them (6). If temperatures become too warm for trout on only one day in the year, that stream ceases to be a trout stream (47). Highest stream temperatures during the day usually occur between 2 and 4 p.m. and peak temperatures usually occur after a succession of warm days and nights. Few trout, even the most tolerant species, can survive temperatures above 82 to 83 degrees Fahrenheit even for very short periods (44) (24). During the summer of 1930, the senior author found rainbow trout living in the South Branch of the Pere Marquette river in Michigan at a peak temperature of 83 degrees Fahrenheit. This temperature occurred for a short time between 3 and 4 p.m. During July, 1931, brook trout survived peak temperatures of 81 and 82 degrees Fahrenheit in the East Branch of the Black river in Michigan.

Studies of trout streams in many portions of the country and observations on the effects of the removal of shade and the raising of stream temperatures has lead the senior author to conclude that water temperatures need not be raised to lethal levels in order to affect trout populations adversely. When stream temperatures are raised so that they consistently exceed 70 degrees Fahrenheit in summer, environmental conditions become less favorable for the cold water species and more favorable for the warm water forms (6). Due to this change in environmental conditions, minnows, suckers, and other warm water fishes may increase in numbers at the expense of the Salmonoids (87) which decrease in numbers to such an extent that sometimes they represent less than ten percent of the total fish population (43) (69).

Fish population studies conducted by the senior author in 1931 and 1935 in the East Branch of the Black river in northern Michigan, indicated that trout comprised 9.6 percent of the total number of fishes and 8.6 percent of the weight of the total population of fishes. Minnows, however, accounted for over 60 percent of the total number of fishes taken and made up 9.6 percent of the total weight of the population. Suckers comprised 23.3 percent of the total number of fishes and 66.7 percent of the weight of all fishes. Studies carried out in 1934 on another warm trout stream, the Pigeon river, indicated that the trout comprised 14.3 to 19.7 percent of the total population; whereas minnows comprised 58 to 68 percent of the population. Fish population studies made during the same period on a cold stream, the West Branch of the Sturgeon river, which lies near to and parallels the Pigeon river, indicated that in the latter stream trout comprised 93.8 to 98.7 percent of the total number of fishes and over 99 percent of the total weight of the population. Shetter and Hazzard (67) found that in the lower portion of the South Branch of the Pine river of Michigan, where the water is fairly warm, trout comprised 13.6 percent of the population, while in a cold stream, the Little Manistee river, they comprise 64 to 91 percent of the population.

In streams inhabited by the warm water species, sunfishes, white bass, black bass, crappie, etc., a slight rise in temperature may increase productivity (78) (33). Temperatures directly lethal to fishes are not so likely to occur in such streams. In the northern portion of the country, bass have been killed by water temperatures of 94 degrees F. (Michigan Lake 1936). In the TVA Reservoirs of northern Alabama water temperatures sometimes reach 96 degrees F. without apparent harmful effects to bass and other native fishes. Near Savannah, Georgia, all fish in a shallow pond died in water which reached 108 degrees F.

The type of bottom material directly affects the productivity of a stream. Shifting sand bottom streams are virtually aquatic deserts (74) while rubble gravel bottoms usually support large populations of aquatic insects (75) (76) (77). The addition of sand, clay, or other inorganic wastes which covers more productive bottom types is, therefore, detrimental to the overall productivity of a stream.

Inert inorganic wastes may be added to streams from a number of sources such as hydraulic and placer mining operations (68), mine tailings, gravel pit washings (89), etc. However, the greatest and most widespread sources of this type of pollutant is soil erosion (7) (17). During the past century floods and soil erosion have been greatly increased in some areas by deforestation (5) (14), fire, overgrazing (30) (41), and ill-advised agricultural practices (34) (86). Materials eroded from the watersheds and washed into streams affect the aquatic environments in a number of ways (48). Sand and silt fill pools, destroy fish cover and spawning beds (35), and cover productive bottom types (45) (46) (52). Erosion and eroded materials have converted good fish streams into wide washes where the low water flow meanders over the wide bottom in a thin sheet or disappears completely in the deposits which choke the former stream channel.

Eroded materials also cause turbidity which affects productivity and water uses. Turbidity decreases light penetration and thereby limits the growth of phytoplankton and other aquatic plants which are of outstanding importance as a basic food for aquatic animals and as a producer of oxygen by photosynthesis (49). The photosynthetic activity of aquatic plants plays an important part in stream reaeration and in the natural purification process (10) (55) (60). Although turbidity prevents or limits algal growth, it does not eliminate the bacterial action which mineralizes organic wastes (13). Thus, turbid waters may transport the bi-products of bacterial action on organic wastes and the effluents of sewage treatment plants considerable distances before they are utilized (83). When the water clears due to impoundment or other causes so that the phytoplankton can grow, these fertilizing materials are utilized and may produce troublesome blooms, or taste and odor problems far from the source of pollution.

Soil washings from eroded areas are usually infertile and generally reduce productivity by choking or covering densely populated rubble gravel riffles, and rich bottom deposits. Washings, from fertile areas, where accelerated erosion is just beginning, or from rich well-fertilized agricultural areas, carry a great deal of nutrient materials into lakes and streams and increase productivity. This fertilizing effect may be so great that huisance blooms of algae may develop each year such as those that occur in many Iowa lakes. These blooms become especially troublesome when domestic sewage is also added to the water (9) (40). Further, in some areas, blooms of toxic algae are frequent and severe (8) (50).

The sole detrimental effect of putrescible wastes is often considered to be oxygen depletion. Putrescible wastes, however, may affect environmental conditions, aquatic life, and water uses in a variety of ways. Organic wastes serve as nutrients which stimulate growth and reproduction of aquatic life (10). The first group to be stimulated are the bacteria which are chiefly responsible for the decomposition and conversion of organic wastes into nutrient materials such as nitrate, phosphate and carbon dioxide (16). If the organic materials occur in sufficient concentration the bacteria may utilize nearly all of the dissolved oxygen and produce conditions which are unfavorable for many other forms of life (9). When such conditions prevail the zone of greatest bacterial growth is designated as a septic zone, in which the species of macro-invertebrates are limited to those organisms that have the ability to live under low oxygen concentrations and those which have adaptations for breathing atmospheric oxygen (3) (31). Although the number of different species of macro-invertebrates occurring in the septic zone, is only a fraction of the number found in the other well-recognized zones of pollution, productivity from the standpoint of numbers and volume of organisms produced is several times that of the other zones (4) (12) (31) (63). This is well-demonstrated in Figure 1 which shows the number of different species and the number and volume of organisms found per unit area under summer conditions in the various pollutional zones of Lytle creek, a small stream near Cincinnati, Ohio, which has been intensively studied by the Public Health Service. This small number of species and very large number of individuals constitute a biological indication of septic conditions (59).

The decomposition of organic wastes by the bacteria converts them into materials such as carbon dioxide, nitrate, and phosphate, which are readily used by phytoplankton. As these materials become available,

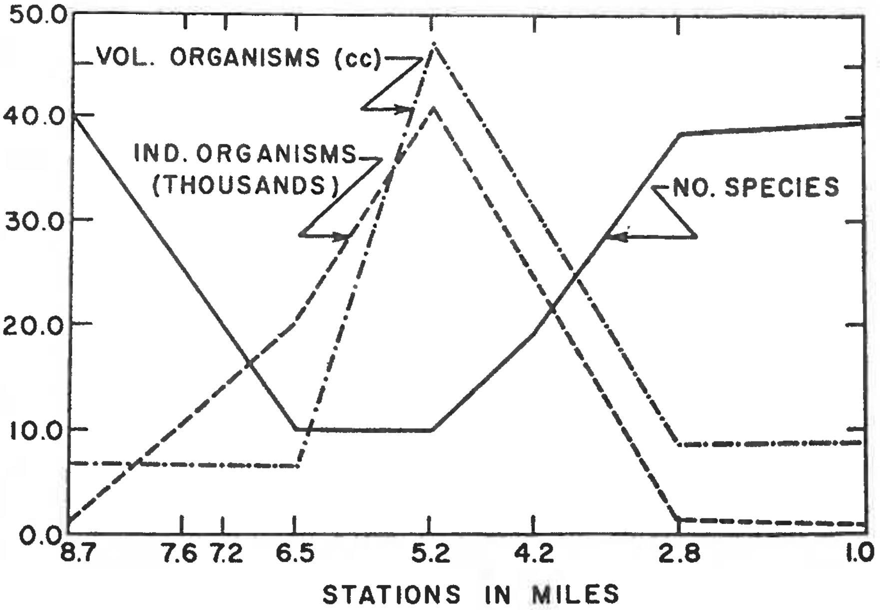

Figure 1 - Macro-invertebrate distribution, Lytle creek, summer conditions.

there is a gradual buildup of phytoplankton in the lower septic zone which reaches its peak in the recovery zone (28). Considerable oxygen is produced by the phytoplankton when conditions are favorable (60). Investigations carried out at the Cincinnati station of the Public Health Service have demonstrated that in many small and moderate sized streams which are fairly clear, reoxygenation by photosynthesis completely overshadows reoxygenation by aeration. Because of the large amounts of food present in the recovery zone of streams polluted with putrescible wastes, phytoplankton populations may become very large and dissolved oxygen levels frequently may exceed saturation by 100 percent (31) (56) (60) (61). In fact, a superabundance of dissolved oxygen may be an indication of organic pollution.

Because photosynthetic activity is dependent upon sunlight there may be wide variations in dissolved oxygen in a polluted stream during the 24-hour daily cycle (31) (38) (60) (66) (70) (84). Dissolved oxygen concentrations are usually highest between 2 and 4 p.m. and are lowest just before or after sunrise. At one station on Lytle creek, dissolved oxygen varied from a high of 19.4 p.p.m. in the afternoon to a low of 0.7 p.p.m. the next morning. The Lytle creek investigations showed that these daily variations in dissolved oxygen are greatest in the late spring and summer seasons and that the difference between maximum and minimum levels is most marked in the recovery zone. Nocturnal-dirunal variations in dissolved oxygen in Lytle creek at different seasons of the year are shown in Figures 2 and 3. It is apparent from these graphs that the season greatly influences minimum oxygen levels.

Year-round studies in Lytle creek and the Great Miami river have indicated a fairly definite seasonal cycle of environmental conditions (31). During the winter months there was an abundance of dissolved oxygen throughout the streams with levels at no time falling far below saturation. During spring as the water becomes warmer, oxygen was depleted just below pollution outfalls during the early morning hours. As the season advanced this oxygenless area increased in extent and duration until in late summer there was a definite septic zone in which oxygen was absent or essentially absent at all times. In Lytle creek there was an almost equal stretch of stream just below this zone in which oxygen was absent or very low during the night. As the fall season advanced the oxygenless zone decreased in extent and duration until by the beginning of winter there was an abundance of oxygen throughout the stream. Character of flow is of great importance in determining the seasonal pattern of stream conditions. If flows are extremely low in winter, septic conditions may persist into December, while if they are high they may not develop in summer.

It will be noted in Figures 2 and 3 that the greatest variations in dissolved oxygen occurred during the spring and summer in the zone of recovery and that concentrations of dissolved oxygen reached a maximum in that zone. These conditions prevailed because, first, phytoplankton growth and photosynthesis reached a peak in the recovery zone, and second, under conditions of supersaturation, riffles and general stream turbulence in the clean water zone brought about the release of oxygen rather than the absorption of additional amounts.

The decomposition of putrescible wastes either by natural purification or by sewage treatment provides a supply of those materials which stimulate the growth of large populations of phytoplankton (10) (28) (91). These algal populations through photosynthetic action aerate the stream and at times produce supersatura-

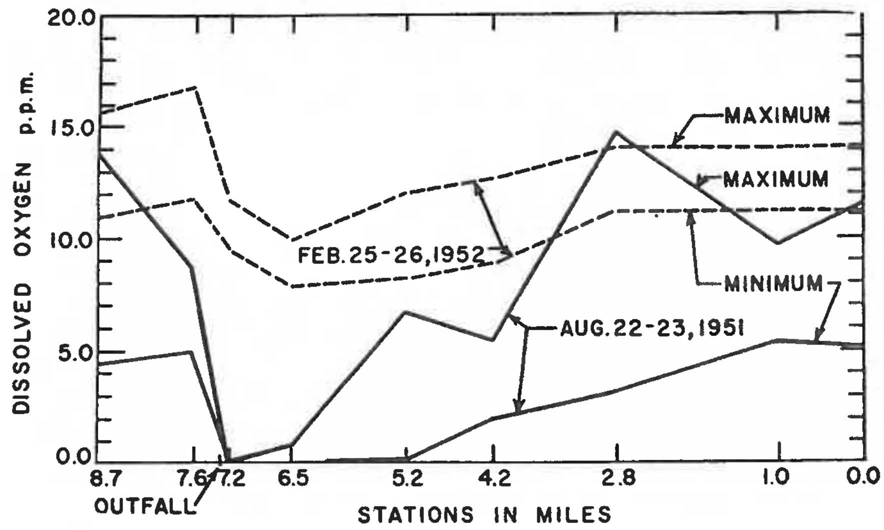

Figure 2 - Range in dissolved oxygen, Lytle creek.

tion (31) (49) (84). There is, however, a point, not definitely known as yet, beyond which the algae cease to be beneficial and may actually be harmful. This is due to the fact that at levels of supersaturation photosynthetic oxygen in streams is rather rapidly released to the atmosphere and this rate of release increases in proportion to the rate of production. Further, while the phytoplankton may produce large quantities of oxygen during the day (61), it also uses oxygen for respiration at all times and during the night excessively large phytoplankton populations may deplete the dissolved oxygen and cause fish kills (49) (54). Such a fish kill occurred in Lytle creek in the fall of 1952. At that time due to extremely low flows of clear water the nutrients in the stream caused an excessive phytoplankton bloom which produced dissolved oxygen levels in excess of 21 p.p.m. in the afternoon but during the night reduced dissolved oxygen levels to such an extent that a severe fish kill occurred in the recovery and clean water zones. It is possible, therefore, for a large secondary sewage treatment plant, located on a small to moderate sized stream, to indirectly cause fish kills through the production of nutrients which bring about excessive growths of algae which in turn deplete the oxygen at night by their respiration and decay.

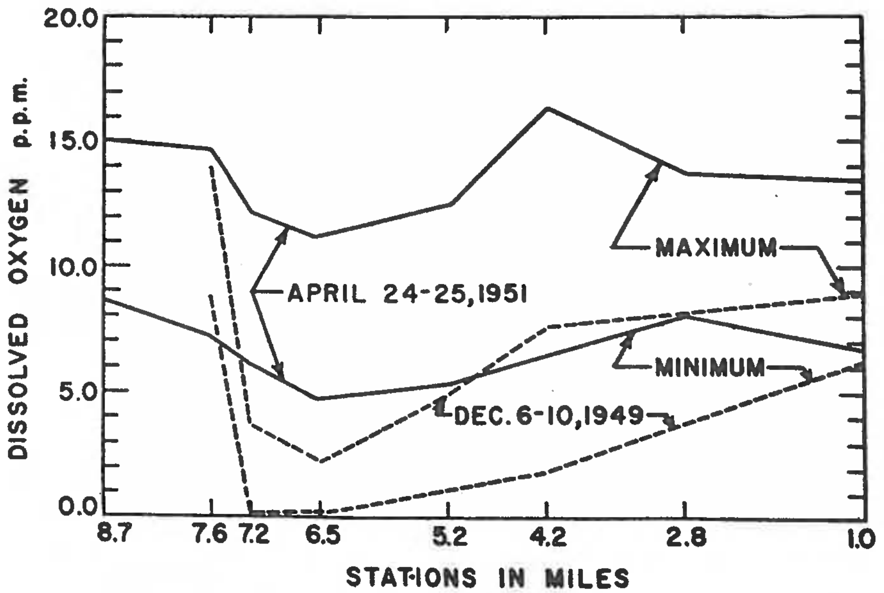

Figure 3 - Range in dissolved oxygen, Lytle creek.

These algal blooms may have other undesirable effects. The algal growths may cause tastes and odors in water supplies farther downstream (93), they may clog filters, or they may create toxic conditions at points of concentration (26) (49) (51) (92). The constant addition of even low levels of nitrogen and phorphorus, no greater than those which may occur naturally, can greatly stimulate algal growths (32). Under natural conditions available phosphates and nitrogen are rather rapidly utilized and bound up in the bodies of the phytoplankton. Studies made by Wiebe (personal communication) in Norris Reservoir, Tennessee, for example, indicated that all of the available phosphorus was utilized in the upper half of the reservoir. In reservoirs, nutrients are also removed by the dying and settling out of the plankters (90). If there are periodic floods which bring in silt that covers the dead organisms which have settled to the bottom, fertility is permanently removed from the reservoir. However, if they are not covered with silt and stratification occurs in the reservoir, they may be decomposed by bacterial action and the nutrient materials may be recirculated throughout the reservoir by the spring and fall overturns. In lakes which are stratified, this is considered to be a basic cause of the spring and fall peaks in plankton growths (90). Reservoirs may, therefore, remove or create problems, depending on conditions. Their mode of operation also influences downstream conditions (83).

In streams severely polluted with organic wastes the stream bottom in the septic zone is usually covered with grayish growths commonly referred to as "sewage fungus" (58) (91). These growths are often regarded as being a result of oxygen deficiencies because they are generally limited to septic areas during the season in which stream surveys are most often conducted. It has been shown, however, that these prolific growths are not produced by oxygen deficiencies but by concentrations of organic matter, chiefly nitrogenous and carbohydrate material (11). The low oxygen concentrations usually associated with them are incidental and the result of the decomposition of the organic material upon which they are dependent for existence. The common designation of these growths as "sewage fungus" is somewhat unfortunate because, while they may contain some fungi such as Geotrichum, Leptomitas, and Fusarium, they are often chiefly composed of the bacteria Sphaerotilus, Zoogloea, and Beggiatoa, and certain ciliated protozoans such as Vorticella, and Carchesium (11) (59). Taken collectively these organisms constitute a pollutional blanket which influences natural purification and other stream life in such ways as the breaking of the natural food cycle in the stream and creating an unfavorable bottom condition.

The year round studies which have been carried out on Lytle creek have demonstrated that when floods are not too severe during the winter months, there is a downstream extension of this pollutional blanket. This is brought about by a change in environment conditions which are more favorable for such growths; namely, an increase in the organic content in the water in the lower zones (36). This increase of organic matter further downstream in winter is believed to be chiefly due to two factors, first, a reduction in the time of flow to about one-fifth that of the summer period due to larger flows, and second, to low water temperatures which decrease metabolic activity of the bacteria and thus the rate of decomposition of the organic matter. The down stream extension of the pollutional blanket covers the bottom and alters the habitat so that it is unfavorable to most of the macro aquatic invertebrates which normally occur in the recovery and upper clean water zones, with the result that they must migrate or die. Its direct effect on the larger forms was well illustrated by the fate of stoneflies, mayflies, caddis flies, and other insects which were washed into polluted sections of Lytle creek. These insects soon became so covered with growths that they were overwhelmed and smothered. The accumulations of these growths on some mayflies, stoneflies, dragonflies, and other insects which were taken under such conditions are shown in Figures 4 and 5. In these figures normal insects are included to enable comparison with those which have been covered with the growths. The pollutional blanket does not develop if severe floods occur during the winter period. It develops during periods of normal or low water and it is removed by the first flood. After its removal the area is practically barren of bottom life and some time is required for it to be repopulated.

Seining studies demonstrated that fish were forced downstream during the period of existence of the pollutional blanket. In fact, although dissolved oxygen concentrations were near saturation throughout Lytle creek during the winter months the fishless area was about twice as long as it was in the summer months. This movement downstream of the fish population was probably due to the destruction of their normal food by the pollutional blanket. It is evident, therefore, that oxygen depletion is not the only factor responsible for the creation of fishless areas in streams polluted with organic wastes.

In instances of organic pollution it is generally assumed that the critically low oxygen levels which occur in streams in late summer during periods of low flow and high temperatures most seriously affect the overall economy of the stream. While this is generally true it may not always be the case. Observations have indicated that in small streams under such conditions increased metabolic activity plus very slow flows have resulted in greatly shortened septic zones. Further, if the water is clear, reaeration due to the photosynthetic activity of the phytoplankton builds up oxygen levels in the recovery zone such that the fishless zone is at a minimum. In addition, low water and slack current allows the settling out of a great deal of material so that it is for the time being removed from the stream. However, the first real rise in stream flow usually picks up these sludge beds and may create a real problem. Studies on the Great Miami river indicate that the first high water after an extended low water period picks up sludge beds and carries them farther downstream with a resultant critical decrease in dissolved oxygen over a more extensive area than was previously affected. The harmful effects of the removal of accumulated sludge beds have been noted by several investigators (9) (59) (88). Forbes (27) noted fish kills in the Illinois and Rock rivers due to the flushing out of sludge beds

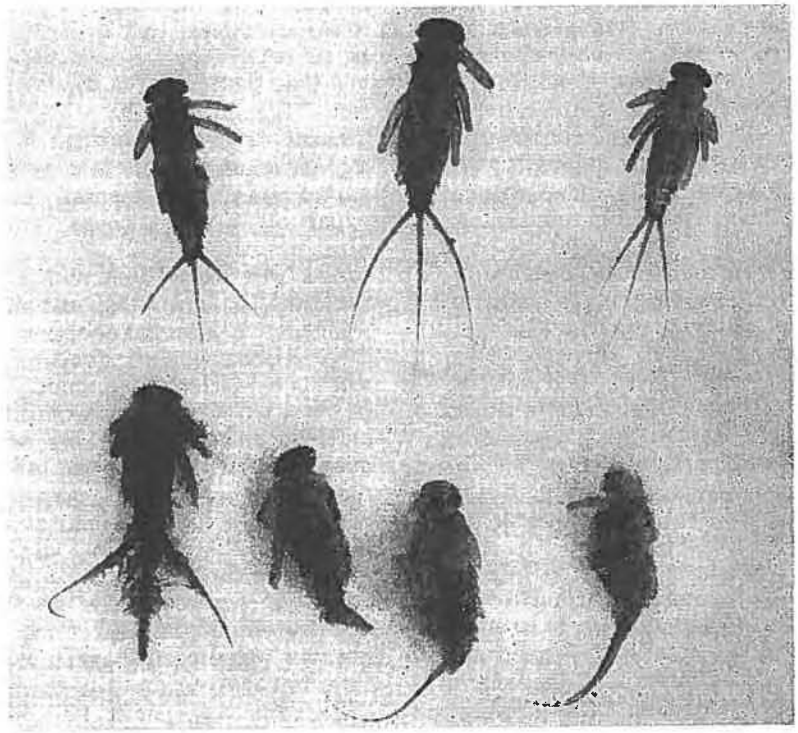

Figure 4 - Upper row, normal mayflies. Lower row, those which have been covered with "sewage fungus" (bacteria and protozoa).

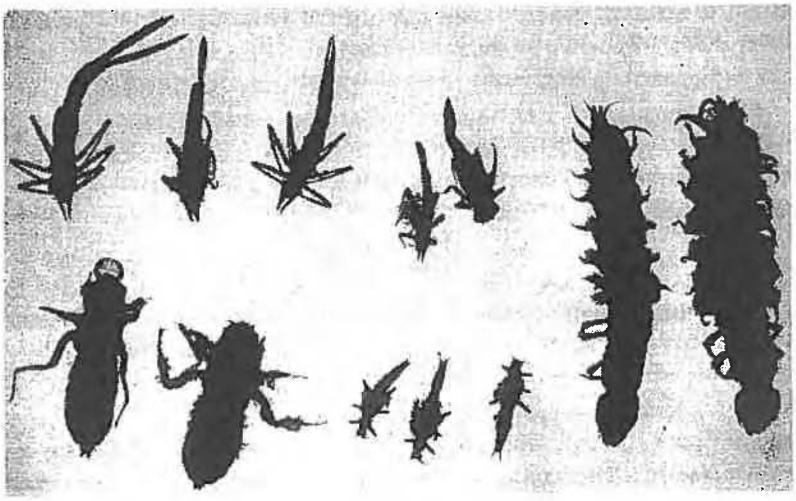

Figure 5 - Growths which develop on aquatic insects in polluted streams due to the downstream extension of the pollutional blanket (sewage fungus). Normal specimens are included for comparison. It can be noted how the gills are covered by the growth.

which had accumulated during periods of low water. The removal of settleable solids is, therefore, of value for the protection of stream life.

Toxic wastes may eliminate the fish population in certain areas or they may decimate only certain species or certain developmental stages. Thus, adults may migrate into an area and live where reproduction is not successful. Some fish food organisms are more sensitive to certain toxic materials than are fish (1). In such instances fish populations may be reduced due to lack of food without actually killing the fish. In addition to destroying fish, toxic wastes may interfere with the natural purification process by limiting those organisms which break down the wastes. If these wastes are to be controlled, their mode of action and their influence on aquatic life must be considered (19) (20) (22). Materials toxic to aquatic life can most readily be detected and their strength estimated by means of bioassays (21) (23).

The character of the water and its mineral content can alter considerably the toxic effects of a given chemical or waste (21). For example, an acid waste added to a highly alkaline stream may be much less toxic than it is when added to an acid stream (18). The reverse is true for alkaline wastes. Further, ammonia salts are much more toxic to fish at high pH levels while copper and other heavy metals are more toxic in soft acid waters. Antagonism and synergy are also of great importance. For example, it has been demonstrated that when salts of copper and zinc occur together they are several times as toxic as when they occur separately at comparable concentrations (84). It is evident, therefore, that the toxicity of wastes cannot be represented in chemical terms alone but should be combined with data secured by means of bioassays.

DISCUSSION

The foregoing has served to indicate that various types of pollutants may have a variety of effects on streams and their biota. Environmental conditions, which largely govern the natural purification process, vary widely in different streams. The capacity to assimilate and purify wastes and the rate of purification, therefore, is not a constant for all streams. Surveys designed to evaluate pollutional conditions and the ability of a stream to assimilate wastes must give full consideration to these environmental conditions.

While dissolved oxygen is of great importance it is only one of a complex of factors which constitute the aquatic environment. The species composition of the aquatic population in a given area is determined by the environmental conditions which have prevailed during the developmental period of the organisms involved (61). If at any time during its development, environmental conditions become lethal for a given organism, that organism will be eliminated even though the unfavorable conditions are of very short duration (9) (47). The aquatic population which occurs in a given area is, therefore, a representation or indicator of environmental conditions which have prevailed during the life history of the organisms comprising the population (3) (15) (53) (63). It is this property of indicating past environmental conditions, especially the extreme conditions of brief duration, that make aquatic populations such valuable indicators of pollution (25) (31) (42). In using biological indicators, however, single species do not possess high index value. Our Studies have indicated that it is the qualitative and quantitative composition of the population which is of importance in denoting past conditions. Further, the absence of clean water species is much more significant than the presence of tolerant species (31) (62).

Data on fish populations are especially valuable for indicating pollutional conditions because fish are the chief end product of the aquatic cycle. Data on the qualitative and quantitative composition of fish populations, rate of growth, average size, and catch per unit effort of the sport and commercial fishery are especially valuable for denoting the suitability of water conditions and the economic and recreational losses due to pollution. In fact the suitability of a water for fish life is best defined by its productivity.

Pollution affects fish populations in a number of ways depending upon the nature and concentration of the waste. Moderate amounts of organic materials which do not seriously affect dissolved oxygen levels, may serve as nutrient materials and increase fish production. This occurred in the Illinois river prior to 1920 (29).

Periodic fish kills due to spills attract a great deal of attention but they are, in general, much less harmful than the slow gradual increase in pollution which slowly decimates the population in such a way that the dead fish, or the decline in the fish population, are not noted and the fishery is destroyed without exciting public protest. In some streams in the east fisheries values have been gradually reduced over such a long period that the fishery potentials are not now generally realized (39).

Although extensive areas of streams are often made fishless the effects of pollution are not always on an all-or-none basis (62). The complete absence of fish is usually common information, but deteriorations in the quality of the population is not generally apparent without some sampling studies. In polluted streams the game fishes may be reduced in number or eliminated while the coarse species or those most tolerant of low oxygen concentrations comprise the remaining population (37). It has been the senior author's experience that when coarse fishes become abundant, they crowd out the game fishes which results in a marked decline in the sport fishery because the coarse fishes are not desired by the sportsmen and are inferior as food fishes (79) (80) (81) (82).

A somewhat routine procedure has grown up and been adopted for pollutional surveys. In these surveys, very often most of the effort is devoted to measurements of the discharge from various plants; to routine bacteriological, physical, and chemical studies of selected effluents; and to a compilation of existing data on domestic and industrial water uses, stream flows, sources of pollution, and sewage treatment. The physical, chemical, and bacteriological studies on the pollutants being discharged into the stream usually include determinations for D.O., B.O.D., pH, temperature, turbidity, settleable solids, total alkalinity, the coliform index, and others depending upon the nature of the waste discharged (2).

Sampling in the receiving stream is usually limited in scope and carried out during the period of low flow and high temperatures. It is customarily confined to the taking of grab samples at selected stations which are often highway bridges. Determinations made on these stream samples are generally the same as those made on the pollutional effluents.

All these studies can be worthwhile and are essential in many instances but their adequacy and value for meeting the overall problem would be greatly increased if some additional studies were made and a somewhat different approach were adopted. The collection, abstracting, rearranging, and assembling of existing data, the routine collection and analysis of samples, and the use of empirical constants and formulae may lead to a "cook book" approach to the overall pollution problem and the concept of the stream as a biological entity is lost.

Further, the routine application of the customary survey procedures can result in wasted time and effort. An example is the routine determination of B.O.D.'s and the coliform index for a waste, the detrimental effect of which is toxicity. Repeatedly, survey groups which go into the field to investigate one of the common biological effects of pollution, a fish kill, follow the customary chemical approach and carry into the field only equipment for the collection and analysis of water samples. Ordinarily no biological observations or studies are made. Further, when samples of the supposedly offending waste are brought into the laboratory an indirect approach is customarily used. First consideration is usually given to B.O.D. or oxygen consumed tests. When the possibility of toxicity is considered and the highly toxic materials, for which routine methods of analyses have been developed, are not found, little thought is given to the probability of the presence of those highly toxic materials which are not readily separated and measured chemically (19). If some of the more toxic substances are indicated by the analyses, their toxicity to aquatic life is frequently estimated on the basis of a limited knowledge of their toxicity in simple solution. Consideration is not given to the fact that the quality of the receiving water greatly influences their toxicity, or that they occur not alone, but in mixtures, and their action may be greatly modified by antagonism and synergy.

The simplest and most direct approach for determining toxicity which takes into consideration all these factors is to make a bioassay of the waste in question, using local species of fish as reagents and employing the receiving water for dilution of the waste. When bioassays are combined with chemical studies for toxicity determinations, much more progress will be made toward detecting, analyzing, and meeting toxic waste problems.

Considerable attention has been devoted to the development of procedures for estimating the dissolved oxygen levels that may be present at critical times of the year or during periods of recorded low flows. Customarily, the data on which these calculations are based are secured from grab samples taken without regard to photosynthetic activity and diurnal variations in dissolved oxygen (72) (85). When collecting data from the calculation of the sag curve attention should be directed not only to variations in water level, rate of flow, temperatures, and the character of the stream, but also to photosynthetic activity and the time of day during which samples are taken. From the standpoint of the protection of fish life, averages of dissolved oxygen concentrations determined from grab samples, are of little value and may be actually misleading unless the determinations on which the averages are based are taken at the correct times and minimal levels are known. It is the extreme and not the average conditions which are important.

Grab samples taken without reference to daily fluctuations in D.O. concentrations or the zones of pollution do not give an adequate or accurate measure of oxygen conditions in a stream. Further, in the calculation of sag curves, photosynthetic activity is neglected (71), even though in many streams it completely overshadows reaeration from the atmosphere and is at its peak during periods of low flow and clear water. In addition, much still remains to be learned concerning the effects of sludge deposits and the relation between the breaking down of the wastes under the controlled conditions in the B.O.D. test and what actually occurs in the stream. It has been shown that all wastes are not broken down at the same rate and that nitrification begins before the fifth day (65). The problem is not simply the amount of pollution discharged. It involves the fate of the waste materials in the stream under varying seasonal conditions, the capacity of the stream for handling that particular waste, and the effects on aquatic life of recreational and economic importance.

If environmental changes brought about in a stream due to pollution cannot be observed or measured, there is justification for estimating them inferentially. However, since the toxicity of wastes to fish life can be determined directly by bioassays, the direct effects of pollution on the aquatic biota can be determined by observation and population studies. Because the aquatic biota present in a stream or stream section serves to indicate past environmental or pollutional conditions, it is evident that the inferential approach is not always necessary. Since acceptable dissolved oxygen concentrations and regulations governing the discharge of toxic wastes are frequently set up to meet the requirements for fish life, and because the natural purification of putrescible wastes in streams is a biological process, the necessity of biological studies to supply pertinent information and to supplement and strengthen the customary stream investigations is apparent.

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BIOLOGICAL INDICES OF WATER POLLUTION WITH SPECIAL REFERENCE TO FISH POPULATIONS*

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A number of investigators have very recently published discussions having to do with biological indices and biological measures of water pollution (1) (2) (7) (13) (14) (15) (16) (26) (27) (28) (29) (30) (36) (38). Fjerdingstad (12) has discussed some of the pertinent European literature. The fundamental concepts presented by these authors are not original, for the idea that aquatic organisms can be useful "indicators" of environmental conditions, and particularly of the degree of pollution of water with organic wastes, has a long history (12). Because of certain novel features and the relatively wide scope of the studies, and the broad implications of some of the conclusions, the work of Patrick (26) (27) (28) (29) (30) has attracted much attention in the United States and seems to deserve the closest scrutiny.

Although much has been written about the various biological indices, there has been no general agreement among the authors as to the meaning of some of the most important terms used in this literature and little effort to clarify the terminology. In view of the variety of backgrounds and dominant interests of individuals concerned with waste disposal and with the effects of wastes on receiving streams, it is not surprising that the term "pollution" does not have exactly the same meaning for all. It is regrettable that a variety of meanings have come to be associated with technical terms such as "biological indicator of pollution". Some of the differences of opinion as to what the biological indices are and what may be their utility doubtless stem from a lack of agreement on the meaning of the word "pollution". Investigators proposing the use of different indicators of pollution should have clarified, it would seem, their ideas as to just what constitutes pollution, or, in other words, exactly what it is that the indicators can be expected to indicate. Too often this has not been done, or the ideas and definitions presented have not been carefully developed and appear to be unsound from a practical standpoint.

Should the mere change (physical, chemical, or biological) of some aquatic environment resulting from waste disposal be regarded as pollution even when ordinary human use and enjoyment of the water and of associated natural resources have not been affected adversely? When there is evidence of environmental change, is this always reliable evidence of damage to a valuable natural resource? May not certain beneficial uses of water be sometimes seriously interfered with by the introduction of wastes which may cause little or no detectable alteration of biological communities? Have there been any studies which have conclusively demonstrated a useable fixed relation between the biological indices of pollution and the actual fate or change in value of aquatic resources which are subject to damage by pollution? If water pollution can be the result of introduction of any of a great variety of substances, organic and inorganic, is it proper to refer to those biotic responses which are only known to occur in the presence of putrescible organic wastes (i.e. to organic enrichment of water) as "indices of pollution"? Can there be any general biological solution for all problems of detection and measurement of water pollution, or is effort being wasted in a search for such a general solution? Are broad limnological investigations being undertaken where intensive study and appraisal of supposedly damaged natural resources of obvious value to man would be more profitable? Is immediate practical value of research results being claimed improperly in an effort to justify fundamental limnological studies for which no such justification should be necessary? These are questions which all biologists interested in water pollution should perhaps ask themselves. Many of these questions have no categorical answer, but it is hoped that the following discussion will prove thought-provoking. It may not only call attention to certain inconsistencies in claims made and terminology used, but may also indicate the need for revision of objectives or a change of emphasis in pertinent future investigations.

Biological investigation now is an integral part of water pollution detection and control, and biologists have become increasingly aware of their opportunities for contributing to progress in this field of work. Their ideas have been solicited and have been well received by other specialists. In trying to aid the advancement of their science, biologists owe it to their profession

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to seek thorough understanding of the practical problems of water pollution control. Understanding the complexity of these problems will make apparent the need for thorough and critical testing of new ideas previous to their widespread practical application.

First, it is necessary to consider the meaning of the term "pollution". The introduction of any foreign substance which merely alters the natural quality of water without materially interfering with any likely use of the water cannot be said in a practical sense to constitute pollution. Virtually every stream and lake in any inhabited region receives at least a trace of something which measurably or not measurably alters the natural quality of the water. What is significant or important from a practical standpoint is not the mere presence of the added material, but its influence upon the economic and esthetic value of the water, or on human welfare in a broad sense. It appears that most authorities in the field of water pollution control and abatement agree in defining water pollution as an impairment of the suitability of water for any beneficial human use, actual or potential, by any foreign material added thereto.

This definition agrees with repeatedly expressed judicial opinion, that is, with definitions of "pollution" and of "clean water" established by courts of law. The following legal definition, cited on page 100 of "Water Quality Criteria", a publication of the California State Water Pollution Control Board (4) is typical: "For the purposes of this case, the word 'pollution' means an impairment, with attendant injury, to the use of water that plaintiffs are entitled to make. Unless the introduction of extraneous matter so unfavorably affects such use, the condition created is short of pollution. In reality, the thing forbidden is the injury. The quantity introduced is immaterial." Other definitions cited agree essentially with this one.

In accordance with the above definition of the word pollution, a demonstrable change of some components of the biota of a stream clearly caused by the discharge of some waste into the water is not invariably evidence of pollution, any more than is a demonstrable chemical change. If it cannot be reasonably asserted that a hazard to human health or interference with some beneficial use of the stream such as fishing, must accompany a particular alteration of the biota, the change cannot correctly be said to indicate pollution. Even the discharge of a waste which eliminates virtually all organisms initially present in a very small or temporary stream capable of supporting no aquatic life of any value to man is not necessarily pollution. Oxygen-depleting organic wastes may be thoroughly mineralized in such streams through natural self-purification processes, so that only harmless substances and beneficial plant nutrients may reach larger watercourses to which these streams are tributary.

In agreement with the definition offered above, Beck (1) has defined pollution broadly as "the alteration of any body of water, by man, to such a degree that said body of water loses any of its value as a natural resource."

Patrick (28), on the other hand, has proposed a distinctly different, strictly biological definition. This author defines pollution as "any thing which brings about a reduction in the diversity of aquatic life and eventually destroys the balance of life in a stream." By way of explanation, it is further stated that "As conservationists interested in using rivers today - but not abusing them so that they are damaged in the future - this is the basis on which pollution should be judged. For it is by preserving the biodynamic cycle that the ability of a river to rejuvenate itself is maintained."

Unfortunately it is not clear just what is to be regarded as pollution according to the definition given by Patrick. Is any reduction in the diversity of aquatic life evidence of pollution which will eventually destroy the "balance of life", or only such a severe reduction of the diversity of life that the ability of the stream to "rejuvenate itself" is indeed destroyed? A reduction of species numbers is not always necessarily followed by the eventual destruction of the "balance of life" in a stream and of the ability of the stream to "rejuvenate itself" (i.e., to undergo natural self-purification). Patrick (28) has pointed out that the so-called "food chain" in aquatic environments "consists of many series of interlocking links so that if one series is broken another can take over so that the chain is not destroyed." It is well known, also, that in certain "zones" of streams heavily and continually enriched with organic wastes relatively few animal and plant species are present, as a rule, yet natural purification proceeds at a very rapid rate. Here, as in an efficient trickling filter, an ideally adapted and obviously vigorous, healthy, and in certain respects very well balanced biota of limited variety can exist, and the organic waste is mineralized far more rapidly and efficiently than it could possibly be in a previously uncontaminated stream with its original, primitive biota. The ability of the stream to "rejuvenate itself" certainly cannot be said to have been destroyed, or even impaired.

Thus, a stream can be seriously polluted, in any usual sense of the word, without lasting destruction of the "balance of life" and of self-purification capacity (which balance hardly can be permanent anyway, in any unstable environment). On the other hand, mere reduction of the diversity of aquatic life without impairment of any important "food chain" (i.e., the food supply of valuable fishes, etc.), or interference with existing stream uses, does not necessarily have anything to do with the conservation of natural resources. It appears, therefore, that the last-mentioned definition of pollution is unsatisfactory, from a practical standpoint, no matter how it was meant to be interpreted.

Careful consideration of the other pertinent writings of Patrick and of the proposed method of judging stream conditions leads to the conclusion that probably this author regards any marked reduction of the diversity of aquatic life as evidence of pollution.

Beck (1) states that "Patrick's methods suggest that the bio-dynamic cycle should be maintained in the primitive condition," allowing for no equitable stream use, for "any deviation from the primitive bio-dynamic cycle is interpreted by Patrick as evidence of pollution." Actually Patrick has not suggested that an entirely primitive condition of every stream biota should be maintained and has classified as "healthy" certain stream sections which evidently were not in the primitive state. A diversity of organisms approaching that found under undisturbed or primitive conditions does seem to have been regarded, however, as being characteristic of all "healthy", unpolluted waters. This interpretation of Patrick's views may be right or wrong. In any case, the need for clarification thereof, and for better agreement among biologists as to the meaning of terms too often loosely used, is apparent. It is noteworthy that Patrick's definition of pollution, quoted above, implies that an alteration of water quality cannot be pollution if it has no appreciable effect on the diversity of aquatic life, and it can be interpreted as meaning that a marked reduction of the diversity of aquatic life is always associated with pollutional abuse of the aquatic environment. Probably few if any workers directly concerned with water pollution abatement or control can approve such a definition.

One can hardly maintain that the relative worth of any biological environment depends on the number of species that it supports, rather than on the relative abundance of species of some importance or value to man. The presence of many different weeds does not usually contribute to the value of a pasture. Also, it is not always correct to assume that any marked modification of a natural environment and of its original, primitive biota will result in their economic degradation, that is, a reduction in value. The clearing, irrigation, and cultivation of desert and other almost worthless lands, the application of agricultural and other poisons for the control of various pests and weeds, and many other human activities can, indeed, greatly enhance the value of the affected lands while drastically modifying their biotas and reducing the numbers of species present. Not only the production of valuable crops is thus promoted, but sometimes also the production of equally valuable wild game. On the other hand, the destruction of only one or a few animal or plant species of outstanding value (e.g., by some selective poison) obviously can mean great loss. This loss is in no way ameliorated by the fact that most of the organisms in the same environment are not noticeably affected. It is evident that a change of any biota considered as a whole (e.g., the number of species represented, etc.) may not be a direct nor always reliable index and measure of damage to any valuable natural resource. There seems to be no sound basis for a general assumption of their strict or even approximate parallelism.

Although most authors evidently have recognized the economic significance of pollution, it appears that when devising their biological indices and measures of water pollution and its severity some biologists have completely disregarded all economic considerations. They seem to have curiously attached at least as much importance to the elimination of any species of diatom, protozoan, rotifer, or insect as to the disappearance of the most valuable food or game fish species. Yet, some have claimed that their measure of the harmful effects of pollution is a direct measure and therefore is more reliable than any chemical evidence or measure of pollution. Why the fate of harmless algal, protozoan or insect species can be said to indicate directly the extent of damage to a valuable fish population or to any commercial, recreational, or other use of water has not been explained.

If biological indices and measures of the severity of pollution cannot be relied upon always to reveal even the extent of damage to valuable aquatic life, they certainly do not indicate accurately the general pollutional status of any water. Water which is rendered biologically sterile by addition of some substances such as chlorine, or is appreciably enriched with some organic wastes, other than domestic sewage, may be of good sanitary quality and suitable for most ordinary domestic, agricultural, and industrial uses. On the other hand, water in which aquatic life is not markedly and adversely affected can be contaminated with dangerous pathogens or with chemicals which may seriously interfere with one or more of the above-mentioned uses. In view of the great variety of water uses, and the number and complexity of considerations (physical, chemical, biological, psychological, economic, and sociological) which evidently must enter into any reliable determination of the degree of interference with these uses by pollution, the evaluation of the over-all pollutional damage cannot be a simple matter. Any contention that some biological observations alone can cut across all of this complexity and show clearly whether the actual and potential uses of a stream have or have not been affected, and the magnitude of the total damage, would appear to be an oversimplification of the problem. It must be admitted that probably nobody has come forth yet with a clear statement of this claim. An yet, unless a different meaning is made perfectly clear, is not this claim implicit in every asseration to the effect that a generally applicable and reliable biological index or measure of the pollutional status or condition of streams has been devised and developed?

Biotic responses to all of the numerous and very different water pollutants are not alike. Early students of water pollution (23) (24) (31) dealt chiefly with pollution by putrescible organic wastes and particularly domestic sewage. In their day, the use of the term "biological indicators of pollution" when referring to organisms which respond in a certain way to heavy organic enrichment of their medium was perhaps justifiable. Untreated or inadequately treated domestic sewage then was by far the most important and perhaps the only well known and generally recognized water pollutant. Its discharge into public waters in amounts sufficient to bring about appreciable biotic changes being usually a hazard to human health, it was and is almost always pollution in any ordinary sense of the word. Today, the importance of pollutants other than domestic sewage is generally recognized. Yet, many authors still speak of "pollution indicators" when they actually are referring only to indicators of organic enrichment of water with putrescible organic wastes, which may or may not involve demonstrable damage to natural resources. Some readers are known to have been misled by this terminology, believing that the same biological indices are useful in detecting every kind of pollution.

Gaufin and Tarzwell (13), when reporting their studies of stream pollution with domestic sewage, obviously were considering the effects on aquatic life of an oxygen-depleting organic waste only. Nevertheless, such unqualified and seemingly general statements as their conclusion that "Pollutional associations are characterized by few species but large numbers of individuals" can be misleading. As the quoted authors well know, the numbers of many organisms initially present are reduced and the numbers of none are markedly increased in some waters polluted with toxic wastes, suspended solids such as silt, or even oxygen-depleting organic wastes discharged intermittently. These authors undoubtedly did not intend the conclusion in question to be a very broad generalization from their observational results having to do with one kind of pollution only. Their use of the expression "pollutional associations" for designating associations found in waters polluted with domestic sewage, or in waters enriched with putrescible organic matter, can be excused on the ground that no term that is more appropriate than the term "pollutional" has come into general use in the biological literature. Yet, this lack of a more precise terminology is not any less deplorable because the use of inappropriate terms, and terms which are not sufficiently specific, has become prevalent.

Beck (1) (2) explicitly confines his discussion to the subject of "organic pollution". He has proposed the use of a numerical "biotic index", which is said to be "indicative of the cleanliness (with regard to organic pollution) of a portion of a stream or lake" (2). He recognizes that his methods are "confined to fresh waters and encroaching salinity has a marked effect on the fauna of a stream." Inasmuch as many different pollutants, including toxic constituents of some organic wastes, likewise can have a marked effect on the fauna of a stream, it is apparent that Beck's methods may have only very limited applicability. It may be usable only in connection with the investigation and description of waters known in advance to contain no pollutants other than non-toxic putrescible organic matter.

Patrick (26) (27) (28), recognizing the importance of a variety of pollutants, apparently has attempted to devise a general procedure for the reliable biological detection and measurement of the different kinds of pollution. For reasons already indicated, however, this desirable objective appears to be attainable only when one defines pollution as "any thing which brings about a reduction in the diversity of aquatic life", which is not a generally acceptable definition.

Wurtz (38), while evidently realizing the existence and importance of a large variety of pollutants, seems to overlook completely the important differences of biotic responses to the different pollutants. Thus, his Figure 1 suggests that the same pollutional zones, including a "degradation zone" extending from the point of mixing of an effluent with the water of a stream to a "polluted zone" located some distance downstream, can be expected to occur in any heavily polluted stream, regardless of the nature of the pollutant (i.e., whether it be "organic", "toxic", or "physical"). Furthermore, he speaks of "pollution tolerant species" and of "non-tolerant organisms", suggesting that organisms are consistently tolerant or consistently non-tolerant with respect to all pollutants. Nowhere does he specify that he has in mind resistance to putrescible organic pollutants only, and there is considerable evidence that he has in mind all pollutants. In large degree, Wurtz seems to have adopted methods similar to Patrick's, but one of his innovations seems to require the probably impossible classification of all or nearly all aquatic organisms as "tolerant" and "non-tolerant" to all kinds of pollution, including the various toxicants, etc. Unfortunately, Wurtz does not include in his paper a list of all organisms considered by him to be tolerant and all those thought to be non-tolerant.

There can be no doubt that some of the so-called "pollution-tolerant" organisms, which actually are simply forms known to thrive in waters markedly enriched with organic wastes, are less tolerant with respect to some other water pollutants than a number of the species known as "clean-water" forms. For example, a species of Physa, a genus of snails generally believed to be resistant to organic pollution (1) has been found to be extremely susceptible to dissolved copper. Certain fish (e.g., centrarchids), may fly nymphs, etc., thought to be more susceptible than Physa to the effects of organic pollution, proved much more resistant to copper. An aquatic environment in which "clean-water" organisms are predominant might possibly be more seriously polluted than one with decidedly "pollutional" biota. The biological terminology evidently needs revision, so that the word pollution would not be used synonymously with organic enrichment.

It appears that, in general, very broad significance of the various biological indices of water quality and the severity of pollution has been only assumed and not actually demonstrated. This is well exemplified by the following quotations from the summary of one of Patrick's papers (27): "On the premise that the balanced physiological activities of aquatic life in surface waters are essential for the maintenance of healthy water conditions, it may be assumed that the most direct measure of this biodynamic cycle will indicate the condition of the water." It will be noted that we have here an assumption based upon a rather nebulous premise. Most writers have failed to supply entirely satisfactory, clear definitions of terms used (e.g., "pollution", "health", etc.) to show precisely what it is that they believe they can detect or measure biologically. Others have failed to use defined terms in a manner entirely consistent with their own definitions. The need for demonstration of the validity of some of the most fundamental assumptions concerning the reliability of pollution indices designed for general application has not been satisfied. Some authors seem to be of the opinion that the proof is unnecessary. It must be admitted that investigations designed to provide such proof would be extremely complex and difficult, and it is not likely that the search for this proof would be very rewarding, for there can hardly be a simple, general solution for the problem of pollution detection and measurement. Like a panacea, a general test for all kinds of pollutional damage is something for which biologists and engineers alike probably would be wise not to seek.

The value of fish as indicators of environment conditions and the importance of fish population studies in connection with the estimation of the intensity of water pollution now can be considered. Doubtless there is much more published information on the environmental requirements of fish than on the requirements of species of any other group of aquatic organisms excepting perhaps a few invertebrate species of outstanding economic importance. The vast quantity of published data relating to the water quality requirements of fish is partly revealed by a few recently prepared compilations and summaries of some of this information (4) (5) (8) (9) (10) (11) (17) (33). The resistance of many fish species to extreme temperatures, to unusual concentrations of dissolved oxygen and other dissolved gases, to variations of water salinity, and to extremes of pH, their susceptibility to the harmful effects of a great variety of toxic substances and of suspended solids of importance as water pollutants, the influence of some of these environmental factors upon embryonic development, growth, and activity, and so forth, have all been studied intensively. There exists also a voluminous literature on the food of fishes, their life history and reproductive requirements, their habitat preferences, movements, avoidance of adverse environmental conditions, and so on.

While it is evident that more is known of the environmental requirements of many fish than is known of the requirements of most, if not all, of the other aquatic organisms often considered as indicators of environmental conditions, the use of fish as indicators has received considerably less attention than has the use of other major groups, plant and animal, microscopic and macroscopic. Fisheries workers recognize the difficulty of adequately sampling fish populations even in bodies of water of moderate size, and this, along with the mobility of fishes, has been advanced as a reason for the unsuitability of fish as indicators of environmental conditions. But, other aquatic groups are difficult to sample too, as Needham and Usinger (25) have demonstrated in the case of the invertebrate macrofauna of a riffle. The difficulty of sampling and the mobility of fishes may not be the chief reasons why fish have not been given more consideration as indicators. The taxonomic groups which have received the most attention no doubt have reflected to some extent the special interests of investigators who happened to be working in the field of water pollution. Fish being the usual economic and recreational yield of stream productivity, their study has obvious applied value and so has required no additional justification. Further, the status of a fish population may indicate suitable or unsuitable environmental conditions, but when knowledge of this population is the end or aim of an investigation, the population status is not regarded as an index of anything else. The value of fish as indicators of the suitability of water for uses other than fishing has not been clearly demonstrated. Whatever the reasons may be, the emphasis in most discussions of the "biological indices" has been on groups other than fish, even though very little is known of the environmental requirements of the species of many of these groups.

The value of knowledge of fish populations in connection with the classification of aquatic environments has not been entirely overlooked. Ricker (32) made important use of the brook trout (Salvelinus fontinalis) and the Centrarchidae and Esocidae as a basis for his ecological classification of certain Ontario streams. Fisheries workers frequently use such expressions as "trout waters" or "bass waters", thus conveniently classifying waters according to the fish species for which the waters are well suited. European workers have made more formal use of such a system of stream classification (34) (37). Brinley and Katzin (3) have classified waters and named various pollutional "zones" of streams in the Ohio River drainage basin according to the kinds of fish populations found therein. As has been done with other animals and plants, some species of fish have been classified as to their "saprobic" preferences by a few authors (22) (24) (19) (35). The basis for such classification of fish is highly questionably. Patrick (26) (27) includes fish among the groups considered in her "biological measure" of stream conditions. Doudoroff (7) and Gaufin and Tarzwell (14) have emphasized the need for thorough fish population studies in connection with water pollution investigations and the determination of the pollutional status of waters.

Studies of fish populations in variously polluted waters, which reveal varying susceptibility of different fish species to pollutional conditions in their natural habitats, have been reported by a number of investigators (3) (6) (11) (20). However, sufficiently intensive sampling of fish populations has not often been undertaken in connection with routine pollution surveys and investigations, the sampling of other aquatic life having been probably more often emphasized when the scope of the biological studies has had to be limited. Inasmuch as it is not often possible adequately to study all of the aquatic biota, including the fish, the practical value of information to be obtained by concentrating attention on fish populations must be carefully weighed against that of information to be derived from equally intensive study of some of the other aquatic organisms, and from comparatively superficial study of the entire biota.

The absence or extreme scarcity of some fish in a stream below the point of entry of a waste, and not above the point of entry, strongly suggests that the waste is somehow detrimental to these fish; if valuable food and game fish species are among those believed to be adversely affected, pollution is indicated. Neither the presence nor the absence of fish is a reliable indication of suitability or unsuitability of water for domestic, agricultural, and industrial uses and for recreational uses other than fishing. Nevertheless, because of the great economic and recreational value of many fish species, this information is essential to sound classification of waters according to their pollutional status.

The presence of fish does not necessarily show that their environment has been suitable for them for a very long time, nor that the species found can survive indefinitely and complete their life cycles under the existing environmental conditions. However, the presence of thriving populations of non-migratory species, including numerous representatives of different age classes whose growth rates have not been subnormal, is significant. It suggests strongly that pollution which is highly detrimental to these fishes and to migratory species whose habitat preferences, natural food, and water quality requirements are quite similar has not occurred recently. For example, the presence of numerous cottids in Northwestern salmon and trout streams which receive organic wastes is believed to indicate that dissolved oxygen concentrations have been adequate for some time and other environmental conditions probably have been suitable not only for the cottids, but also for migratory salmon and trout. There is now no sound reason for believing that the presence of any invertebrate form is a more reliable and appropriate biological indicator of the suitability of past environmental conditions for the migratory salmonids than is the presence of cottids.

The value of waters used for fishing, and of the fisheries which they support, bears no fixed, direct relation to the number of fish species to be found therein, just as it bears no such relation to the number of species of other organisms present. Some 35 species of fish were collected in the Midwestern warm-water stream studied by Katz and Gaufin (20). Because of the scarcity of valuable food and game fishes, this small, polluted stream is not regarded as a valuable fishing stream. On the other hand, many cool, pure streams which are highly valued as trout and salmon streams contain very few fish species other than the salmonids. Indeed, the invasion of valuable trout waters by other fish species not initially present is generally regarded as evidence of degradation of these waters, for the numbers of trout usually decline when it occurs. Such a change of the fish population can be a result of increasing temperatures and probably also of enrichment (18). Warm, eutrophic waters can support a great variety of fish and other organisms, but trout waters which are approaching this condition can hardly be regarded as "healthy".

Some of the above statements seem to contradict Patrick's (26) (27) conclusion, based on a study of the Conestoga River Basin of Pennsylvania, that "The results of this study indicate that under healthy conditions a great many species representing the various taxonomic groups should be present." It is necessary, therefore, to examine the evidence on which the latter conclusion is based. It appears that, in accordance with Patrick's conception of what a "healthy" stream should be like biologically, only those stations where a variety of organisms judged to be fairly normal or typical was actually found were classed as "healthy". It is not surprising, therefore, that all of the stations classed as "healthy" had indeed this large variety of organisms. Chemical, bacteriological, and other data were collected and considered in selecting and classifying the stations studied. It is clearly indicated, however, that the variety of organisms found (which is the proposed index or measure of stream "health") also was a major consideration. Different conclusions perhaps would have been reached had the initial classification of the stations been based entirely on other criteria of obvious practical import (such as the abundance, condition, and growth rates of valuable native game fish, etc.) and had a greater variety of natural, unpolluted streams been examined. It is noteworthy also that certain stations which evidently were not much affected by waste discharges but lacked the usual variety of organisms (e.g., Station No. 152, in a stream section evidently suited for stocking with trout) were classed as "atypical" stations by reason of certain observed peculiarities, such as low water temperatures, unusual bottom or shore conditions, etc. Other stations which had the expected variety of organisms were classified as "healthy" stations despite noted peculiarities such as marked organic enrichment, unusually high BOD, high CO_2 content, high bacterial content, or great turbidity of the water. Thus, it appears that the rating of the stations was somewhat arbitrary.

When the possibility of certain pollutional damage specifically to fisheries is under consideration, it should be remembered that fishes have varying ecological requirements and habits, differ in their resistance to variations of water quality, and are not all dependent upon all aquatic organisms, nor upon the same organisms, for their food. It has been shown that the growth of some fish species is promoted in certain waters affected by the discharge of organic waste (21), whereas the same waters apparently are rendered unsuitable for some other species (20). A reduction of the number of species of fish-food organisms, with a great increase of abundance of some of the remaining species, which occur often in streams receiving various wastes, doubtless can be harmless or beneficial for some fish species, although this reduction may be detrimental to others. If they are not otherwise adversely affected by environmental changes, those fishes which can well utilize the abundant food organisms will thrive, while others may disappear. Whether the total effect on fisheries will be favorable or unfavorable clearly will depend on the relative commercial and recreational value of those fish populations which are favored and those which are affected adversely. An intensive study of the entire aquatic biota cannot always reveal the extent of pollutional damage to fisheries, unless the relative value of the various forms present (for man, or as food for important fishes) is considered.

To evaluate the effect of environmental changes on fisheries it is necessary to know what fish species were originally present, how highly each is valued, and in what way and to what degree each important species has been affected by waste discharges. The relative abundance and condition of individuals of different species in the waters under investigation and in suitable "control" areas, the growth-rates of different age classes, the palatability of the flesh, and possible interference with normal migratory movements or with other reproductive activities must all be considered. Fish collections taken by carefully planned netting will yield much of this information. Commercial and sport catch records, showing the take per unit of fishing effort, and various field observations (e.g., of spawning areas utilized, etc.) also can be very helpful. Inasmuch as the presence of wastes and other pollutants is by no means the only factor which can directly influence fish populations, the cause of observed differences of fish populations must be determined. In this connection, studies of the food of important fish species and of the relative abundance of available food organisms in waters which are affected and those which are not affected by waste discharges may be essential. However, if detection and evaluation of pollutional damage to fisheries is the only or primary objective of a biological investigation, an enumeration of the species of organisms of all taxonomic groups, or of some single invertebrate group, cannot be deemed a direct approach to the problem at hand. Judged only by its practical utility, it may be a waste of time, effort, and money, which perhaps could be far better expended on more directly pertinent studies. Indeed, it is difficult to imagine pollutional interference with any use or combination of uses of water which could usually be accurately and most efficiently evaluated in such an indirect manner.

A study of the influence of large amounts of organic waste on the ecology of the Tuolumne River of California has recently been completed by Warren (unpublished data). During August and September of 1952, the daily mean discharge rates of this river at the city of Modesto ranged from 293 to 822 cubic feet per second. The daily mean discharge rates of domestic and cannery waste introduced into the Tuolumne at Modesto ranged from 0 to 22.3 cubic feet per second. The 5-day biochemical oxygen demand of samples of this waste ranged from 60 to 575 parts per million. Dissolved oxygen concentrations at stations below the point of waste discharge ranged from zero to supersaturation during this time.

The objective of this study was to determine some of the effects of organic waste discharges on the ecology of the Tuolumne during the different seasons of the year. Some thirty miles of the river were studied, of which only the lower ten were influenced by waste discharges. The phytoplankton, zooplankton, benthic fauna, and fish were studied along with the physical, chemical, and bacteriological conditions in this river. The fishery phase of the investigation represented a small part of the total effort.

The investigation of the Tuolumne River now being complete and its objective more or less realized, it is interesting to consider how well other objectives might have been satisfied by this same study, planned and conducted as it was. For instance, had the objective been to determine the influence of the organic waste specifically on the fisheries of the Tuolumne, could not much of the effort devoted to the bacteriological, phytoplankton, zooplankton, and benthic faunal investigations have been far better expended on a thorough study of the fisheries? One is forced to conclude that were the objective to determine the status of the fisheries, the fish should have received most of the attention. This does not mean that studies of the plankton and of the benthic fauna are not necessary phases of an investigation so oriented. They may be quite necessary, but they should be so planned that the time and effort devoted thereto would not be out of proportion to their contribution to thorough understanding of the status or condition of the valuable fish populations.

The benthic fauna present at stations on the Tuolumne River below the point of waste discharge had many of the recognized "pollutional" characteristics during late summer and early fall. By this time, many of the "clean-water" species present at these stations earlier in the summer, and persisting at stations above the waste outfall, had disappeared. A marked reduction in species numbers had taken place, and at least one species occurred in unusually great numbers. While the bottom fauna showed changes that in accordance with most biological index methods would be regarded as evidence of pollution, rather intensive seining during mid-September resulted in the collection of 10 species of fish at stations above the point of waste discharge and 12 species at stations within the first ten miles below this point. The variety of fish present had certainly not been greatly altered by the introduction of wastes, even though the bottom fauna had been markedly modified.

Collections of young bluegills (Lepomis macrochirus) made in September showed the O-year class to grow faster at stations below the point of waste introduction than at stations above this point. The size difference persisted in the 1-year class. The difference in the O-year - class growth rates could probably be attributed to the greater abundance of zooplankton at the downstream stations.

While the above data are interesting, they cannot be taken as evidence that pollution of the Tuolumne damaging to fisheries did not exist. Some evidence indicated interference with a portion of the upstream migration of adult chinook salmon (Oncorhynchus tshawytscha), though the downstream migrant young were presumably unaffected, being apparently absent from the Tuolumne by the time of critical summer river flows and waste discharges. Juvenile shad may perhaps have been affected also. Had the principal objective of the Tuolumne River investigation been an evaluation of damage to fisheries resources by pollution, the study could not have been deemed complete in the absence of conclusive evidence that interference with salmon migrations and other possible damage to valuable fish populations had or had not occurred. None of the proposed "biological measures" of pollution intensity could have revealed the degree of such interference or damage. In order to obtain the crucial evidence required, it would have been necessary to emphasize the fisheries phase of the investigation.

It is not the purpose of this paper to discourage limnological research pertinent to water pollution problems, nor is it intended to deny the value of all biological indicators of pollution. There can be no doubt that a drastic modification of any natural aquatic biota, attributable to a change of water quality, can have highly undesirable aspects or consequences. Such changes presumably are detrimental to human use and enjoyment of natural waters more often than they are not. Many a readily demonstrable effect of wastes upon aquatic life in a valuable stream is suggestive of probable existing or incipient pollution which deserves close attention and investigation. Even before valuable fish populations have been materially affected by some potentially harmful pollutant, an observed detrimental effect upon other organisms which are somewhat more susceptible than fish may give warning of possible future damage to fisheries by continued or additional waste discharges. The nature and the source of existing or incipient pollution also may be revealed by appropriate biological indices. Finally, inasmuch as some of the organisms considered to be indicators of pollution are organisms which can directly interfere with human use or enjoyment of waters (e.g., unsightly slime-forming organisms such as Sphaerotilus, odor-producing algae, etc.), their unusual abundance may not be disregarded in evaluating over-all damage caused by pollution.

CONCLUSIONS

It must be concluded that every change or peculiarity of the flora and fauna of a stream which has been referred to as an index or measure of pollution is in reality only an index of environmental disturbance or environmental anomaly. The disturbance or anomaly indicated may or may not be pollutional in the sense that stream uses are interfered with. Pollution (i.e., interference with stream uses) can be negligible when the effect on the aquatic biota as a whole is great, and it can be severe when most of the aquatic life is unaffected. Gross pollution often can be demonstrated without any biological investigation. When biological investigation may be necessary, pollutional damage to valuable aquatic organisms can probably best be determined by concentrating attention upon these particular organisms. Yet, since all aquatic life forms are more or less sensitive to changes of water quality, the fate of any of them theoretically can be instructive, revealing something about the nature and magnitude of these changes that may not be obvious nor easily determined otherwise.

A genuine contribution to water pollution science can be made whenever the presence or relative abundance of living organisms of any kind can be shown to be a reliable index of something tangible that one may need to know in order fully to ascertain and understand the pollutional status of an aquatic environment. When proposing and describing the use of such biological indices, one should state specifically what it is that each is believed to indicate, carefully avoiding such general, vague, or abstract terms as "pollution" and "stream health", which may be variously understood. Does it indicate, for example, continual presence of dissolved oxygen in certain concentrations believed to be adequate for sensitive fish species? Does it indicate organic enrichment likely to interfere in some way other than through oxygen depletion with certain specific uses of water? Or does it indicate that particular toxic substances have not recently been present in concentrations likely to be injurious to fish, to man, or to certain crops? No simple biological indicator and no one measure of stream conditions can indicate all of these things. But any species can become a biological indicator of environmental conditions of possible interest as soon as its nutritional and other environmental requirements, its relative resistance to various toxic substances, etc., become known. Widely distributed sessile or sedentary organisms should be the most useful indicators of past conditions. Unfortunately, the water quality requirements of most of the "indicator organisms" have never been thoroughly investigated, so that there is no real knowledge of specific factors which limit their distribution and abundance. Probably nobody now knows just why any of the so-called clean-water organisms begin to disappear from waters subject to progressively increasing organic enrichment. Here is a field for future research which is far more promising than is, for example, the questionable classification of all aquatic organisms as "pollutional", "clean-water", or "facultative". If there are common sedentary organisms whose water quality requirements can be shown to correspond closely with those of valuable fish species, they are potentially useful indicators. At the present time, however, excepting instances of gross pollution, only fish themselves can be said to indicate reliably environmental conditions generally suitable or unsuitable for their existence.

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BIOACCUMULATION OF RADIOISOTOPES THROUGH AQUATIC FOOD CHAINS*

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INTRODUCTION

With an increasing number of atomic energy installations and their associated problems of disposal of liquid wastes, we recognize that more and more aquatic environments are going to be exposed to at least low concentrations of radioactive materials. For the safety of human populations who may be drinking water which contains such radioactive materials, a set of maximum permissible concentrations has been recommended (International Commission on Radiological Protection, 1955). By themselves, however, such recommendations are inadequate to define completely the radiological hazard which may develop through aquatic food chains. Where biological systems are involved, the organisms may accumulate certain isotopes to many times the initial concentrations in the water. There are many radioisotopes, however, that apparently are not biologically concentrated.

This paper describes some of the mechanisms involved in the accumulation of radioisotopes by aquatic organisms, with special reference to food webs and metabolic rates, and presents some examples of how the concentration of radioisotopes in organisms can be used to measure relationships between different species.

THE ACCUMULATION OF RADIOACTIVE MATERIALS

In order to interpret the reasons for, or to predict the concentration of, radioactive substances in aquatic forms, the biologist must appreciate that several basic processes are involved. The most important are: (1) the mode of uptake, which includes adsorption to exposed areas, absorption into tissues, and assimilation of ingested material; (2) retention, which is a function of the biochemistry of the particular elements and components involved, the site of deposition, the turnover rate, and the radioactive half-life; and (3) the mode of elimination, which may involve ion exchange, diffusion, excretion, and defecation.

MODE OF UPTAKE

The metabolism of the different radioelements and the relative importance of the different modes of uptake will fluctuate widely between different species, environments, and seasons. While this paper is principally concerned with assimilation through food chains, the processes of adsorption and absorption of radioactive substances directly from the water cannot be neglected. They are primary mechanisms by which inorganic materials are acquired by aquatic plants which are the food sources of the animals. The absorption of radioisotopes of strontium, barium-lanthanum and sodium by fresh-water fish has been demonstrated by Prosser et al. (1945). Absorption of radio-calcium has been demonstrated by Lovelace and Podoliak (1952) and by Rosenthal (1956). Chipman (1956) showed that cesium readily passed through excised pieces of tuna skin but that there was little absorption of strontium or ruthenium from sea water. Fish immersed in effluent from the Hanford reactors concentrated Na^{24} in the tissues about 130-fold. Direct absorption of other isotopes which are dominant in the effluent, including Cr^{51}, Cu^{64}, P^{32}, As^{76}, and rare earths, appeared to be inconsequential, however. In fish that live downriver from the Hanford reactors, sorption of radioactive materials directly from the effluents accounts for only about 1.5 percent of the total radioactivity. Consequently, sorption is of much less importance than ingestion in the uptake of radioactive materials by Columbia River fish.

Adsorption occurs almost instantaneously, as has been demonstrated with yttrium on cells of the marine alga Carteria by Rice (1956), while equilibrium by absorption is usually reached by algal cells (Whittaker, 1953) and by vascular aquatic plants (Hayes, et al., 1952) within a few hours. Because of the rapid uptake of radioisotopes by these mechanisms, Columbia River plankton, composed almost entirely of diatoms, appears to reach equilibrium about one hour after floating into the zone containing effluent from the Hanford reactors (Foster and Davis, 1955).

Assimilation of ingested materials is the dominant means by which many radioactive materials become accumulated in animals since the bulk of their essential elements is obtained from their food. The contribution of food webs to the concentration of radioisotopes in aquatic animals was apparent from samples collected from the Columbia River soon after the first Hanford reactors began operation. Fish collected downriver from the reactors were approximately 100 times as radioactive as laboratory fish that were exposed to equivalent mixtures of the effluent, but fed uncontaminated food. Bottom animals, particularly herbivorous insect larvae, were found to be even more radioactive than the fish. The concentrations of radioactive materials in Columbia River organisms have never approached hazardous levels, however.

DIFFERENCES BETWEEN SPECIES

The relative concentrations of beta emitters in various Columbia River organisms are shown in Figure 1. There are several reasons for the differences

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which occur between these species.

(1) Several radioisotopes are involved and their relative proportions are different in the various organisms. A good indication of the proportions of the several isotopes can be obtained from curves like those in Figure 2 which show the characteristics of the radioactive decay of the isotope mixtures peculiar to each species. The positions of the curves in Figure 2 at zero time approximate the relative concentrations of radioisotopes in the water, small fish [Richardsonius balteatus (Richardson)], caddis larvae [Hydropsyche cockerelli, Banks], and plankton of the Columbia River during late summer months. The predominance of short-lived isotopes in the water is shown by the steep slope of the bottom curve. Short-lived emitters also contribute most of the radioactivity in the plankton but these have virtually disappeared by the fifth day. The remaining activity in the plankton, which is only about 20 percent of that originally present, emanates from P^{32} and other isotopes with half-lives greater than two weeks. In the caddis larvae and fish, only about 5 percent of the initial radioactivity originates from short-lived emitters. After the first day the rate of decay is quite uniform and characteristic of P^{32} (half-life 14.3 days). The dominance of the P^{32} has been confirmed by radiochemical analysis.

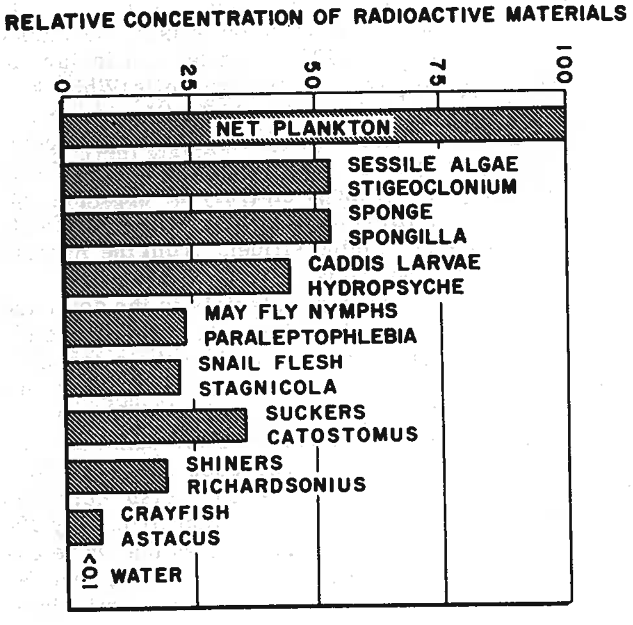

Figure 1 - Radioactivity in different Columbia River organisms.

The relative proportions of the several isotopes differ from one organism to another not only because of dissimilarities in the chemical composition and physiological demands of the different forms but also because of the different sorption characteristics which vary with morphology. Food chains are also important since they tend to "select for" isotopes of the essential elements, in this case P^{32}, and to "select against" nonessential elements. During the late summer months, the concentration of P^{32} in small fish of the Columbia River may be 165,000 time that of the water. On the other hand, As^{76} is barely detectable in the fish although it is responsible for a substantial fraction of the radioactivity in the water.

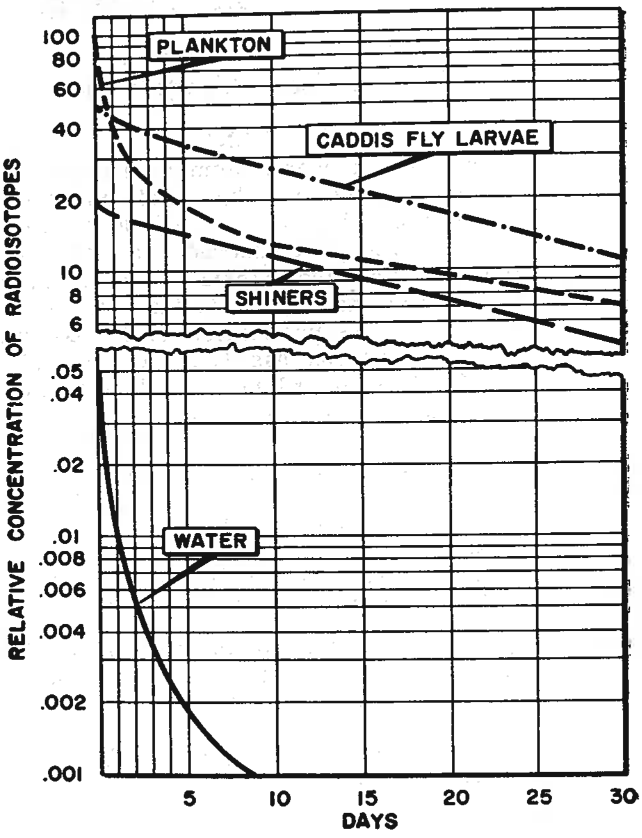

Figure 2 - Radioactive decay in different organisms and Columbia River water.

The marked variation in the relative abundance of different isotopes which can occur at different trophic levels and even between similar species has recently been pointed out by Krumholz (1956). From data collected at White Oak Lake, which received a variety of radioactive wastes from the Oak Ridge National Laboratory, Krumholz states: "Although radiophosphorus was generally accumulated in much greater amounts than any other radioelement by the organisms that served as food for the fish, that element made up only a small portion of the total radiomaterials concentrated in the fish tissues; whereas radiostrontium, which was present in the food organisms in only relatively small quantities, was accumulated in high concentrations in the fish skeletons. Furthermore, although the contents of the bluegill stomachs contained more radioactivity, on the average, than those of the black crappies, the crappies accumulated considerably greater amounts of radiomaterials in the hard tissues than the bluegills did. The bluegills, on the other hand, accumulated more radiomaterials in the soft tissues than the black crappies. Both species concentrated radiostrontium in quantities 20,000 to 30,000 times as great as those in the water in which they lived."

(2) Variation in moisture content between different organisms is a second reason for the differences in concentration of radioisotopes shown in Figure 1. Chemical composition is also a factor since we are

actually concerned with the quantity of a particular element in a unit mass of live tissue. The percentage of the live weight of the Columbia River plankton, caddis larvae, and minnows which is contributed by the inorganic ash is respectively 16, 2.2, and 3.0; and the concentration of phosphorus in the living organisms is about 150 ppm for plankton, 2,000 ppm for caddis larvae, and 6,000 ppm for minnows. Even greater differences may occur between the different tissues of an individual. Figure 3 shows how the concentration of radioactive materials varies between different tissues of whitefish in the Columbia River. Since virtually all of the activity is from P^{32} this gives a good indication of the relative concentration of phosphate in the different tissues.

(3) A third reason for differences in concentrations of radioisotopes between different organisms is their relative position on the food pyramid. Although elements are exchanged continuously between the water and the organisms of a food web, there is a mean retention time for each element in each organism. Each trophic level thus serves as a kind of pool or reservoir in which essential elements are retained for some mean length of time before they are passed on to the next level. The size of each pool will be governed by the total amount of an element held by the entire biotic mass making up the particular trophic level. A major fraction of most radioactive contaminants accumulated by aquatic life will be held by the plankton and benthic algae because of their relatively large total mass. Rigler (1956) found that over 95 percent of the P^{32} added to a lake was taken up by plankton (including bacteria) within 20 minutes. But retention time is not necessarily a function of the size of the pool. Indeed it is more apt to be inversely related since most elements will remain for a longer time in the larger organisms than in the small plant forms, although the small plants constitute the largest pool. Since, in the Columbia River, we are dealing with a flowing stream where isotopes are added at a more or less constant rate, much of the mineral exchange system can be considered as a once-through process rather than a cycle. Some radioactive decay will occur while the isotopes are retained in each trophic level. This decay, and thus the effective retention period, should be measurable by a progressive decline in specific activity -- the concentration of an isotope per unit mass of the element. For example, under certain conditions midge larvae in the Columbia River may contain on the order of 4 μc P^{32}/g of P and the small fish which eat the midge larvae about 0.5 μc P^{32}/g of P . Since the half-life of P^{32} is two weeks, the phophorus deposited in the fish must be, on the average, about six weeks "older" than that in the midge larvae. The reltive "age" of the isotope will differ between species and differ between species and will change with the age, sixe, and growth rate of the individual and with the seasons. The decrease in specific activity will, of course, be more apparent for short-lived isotopes than for those with half-lives of several weeks or more.

The specific activity of the river biota should be appreciably lower than that of the water not merely because of the time required to incorporate the isotope into the organisms but also because of the "pools" of elements fixed in the biota and sediments. When a radioisotope is first introduced into a body of water it

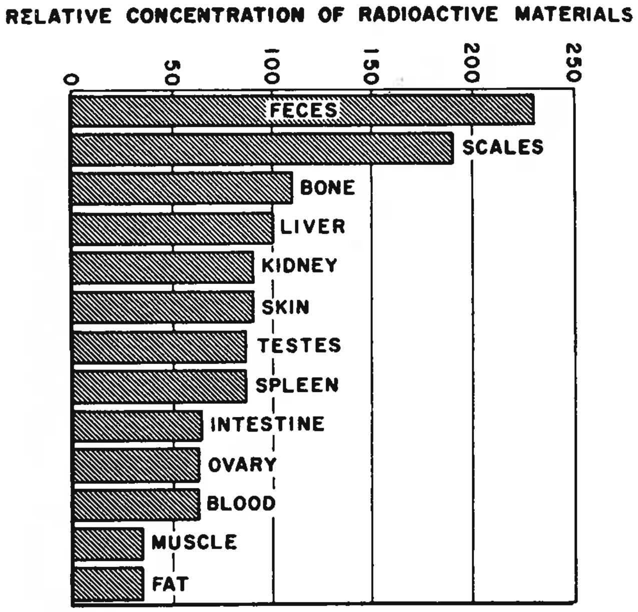

Figure 3 - Radioactivity in different tissues of Columbia River fish.

will be isotopically diluted with the stable form of the element which is dissolved in the water. Soon, it also will become isotopically diluted by exchange with the stable form of the element which has not been in solution. With a single addition of isotope into a "static" environment, the specific activity will eventually become uniform throughout the biota. Reservoirs of phosphates in the solids of lakes have been described by Hutchinson and Bowen (1950) and Hayes and coworkers (1952), who have studied phosphorus exchange with the use of P^{32} .

RATE OF ACCUMULATION BY AQUATIC ORGANISMS

The nearly instantaneous uptake of isotopes by adsorption and the rapid uptake by absorption have been mentioned. When animals are chronically feeding on radioactive materials, the rate at which their concentration of the isotopes approaches equilibrium will be a function of the radioactive and biological half-lives of the particular isotope involved.

Figure 4 shows the rate at which caddis fly larvae (Hydropsyche cockerelli) accumulated radioactive materials (mostly P^{32}) when fed filamentous algae (mostly Spirogyra) that had been cultured in reactor effluent. If there was no biological turnover of phosphorus in the caddis larvae, the time required to reach some fraction of the equilibrium level would be a function of the radioactive decay constant and could be predicted from the equation:

$$\frac{Q_t}{Q_e} = 1 - e^{-\lambda t}$$

where Q_e is the amount of the isotope present at equilibrium, Q_t is the amount present at some time (t) before equilibrium is reached, and λ is the radioactive decay constant.

Since true equilibrium will only be reached after infinite time, we can consider practical equilibrium to occur when $Q_t = 0.9\,Q_e$, and solve the equation for t. For any isotope, t will be equal to the half-life multiplied by $\frac{-\ln 0.1}{.693}$. For P^{32} it is approximately 47 days.

The curve presented in Figure 4 shows a much shorter time which indicates that significant biological turnover is present. The equation is easily modified to take this into account:

$$\frac{Q_t}{Q_e} = 1 - e^{-\delta t}$$

where δ is the sum of λ and β, where β is the constant for biological half-life. A 0.9 of equilibrium,

$$t = \frac{-\ln 0.1}{\beta + \lambda}$$

From Figure 4, t is about 50 hours and

$$50 = \frac{2.302}{\frac{.693}{T_b} + \frac{.693}{343}}$$

(343 is the half-life of P^{32} in hours).

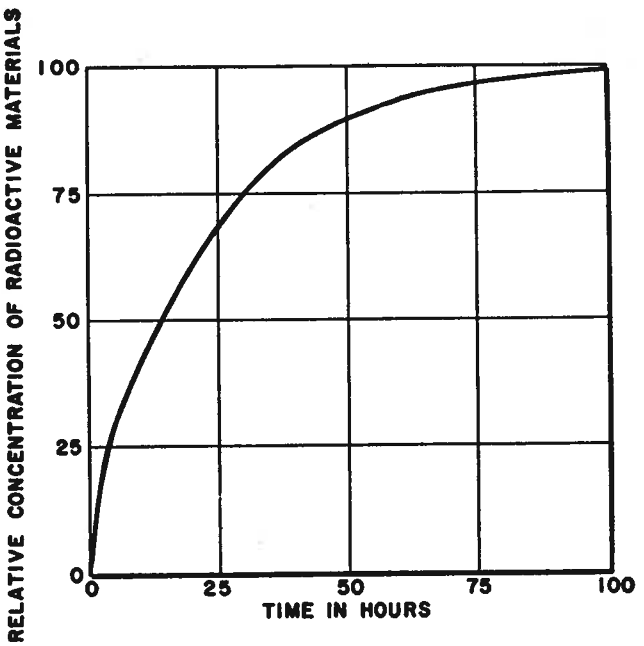

Figure 4 - Rate of accumulation of effluent isotopes by caddis fly larvae.

The biological half-life, T_b, is about 16 hours. Under such conditions the specific activity of the P^{32} will not diminish appreciably at this trophic level.

If laboratory tests can be carried out in conjunction with field observations, some interesting ecological relationships can be deduced. For example, we might measure the concentration of P^{32} in small minnows collected from a contaminated environment and find this to be $2 \times 10^{-3}\,\mu c$/gram. If the average size of the minnows was 5 grams, then each fish would have a body burden of about $10^{-2}\,\mu c$ of P^{32}. From a laboratory test, which duplicated field conditions as closely as possible, we might find that 0.9 of Q_e was reached in 20 days. Then

$$\delta = \frac{-\ln 0.1}{t} = \frac{2.302}{20} = 0.115$$

The same test might show that half of the ingested P^{32} was assimilated and deposited ($a = 0.5$). Assuming the concentration of P^{32} in the river fish to be in equilibrium with the environment and neglecting growth.

$$Q_e = \frac{aq}{\delta}$$

where q is the quantity of P^{32} ingested per unit time -- in this case each day. Then,

$$10^{-2}\,\mu c = \frac{0.5\,q}{0.115}$$

and

$$q = 2.3 \times 10^{-3}\,\mu c/\text{day}.$$

In order to have reached the observed concentration of P^{32}, each minnow must have consumed about $2.3 \times 10^{-3}\,\mu c$ of P^{32} each day. If, from stomach analyses, we have found that the fish feed predominantly on midge larvae and from field collections we have found that the midge larvae have a concentration of P^{32} of about $10^{-2}\,\mu c/g$, then we can surmise that each minnow has been eating about 0.23 grams of the midge larvae each day.

SEASONAL VARIATIONS

Since most aquatic animals are poikilothermic, their metabolic rates, and thus their feeding rates, change with variations in temperature and so with the seasons. For those aquatic forms that accumulate radioactive substances principally via ingestion, the concentration of radioisotopes fluctuates with metabolic rate. Figure 5 shows the seasonal fluctuations which occur in the radioactivity of plankton (diatoms) and minnows (Richardsonius balteatus) in the Columbia River. Fluctuations in plankton are quite similar to those in the water since the radioisotopes are acquired by direct absorption and adsorption (Foster and Davis, 1955). On the other hand, fluctuation in the radioactivity of the minnows is more closely related to the temperature. The 75-fold increase in concentration of radioisotopes in the fish between winter and late summer does not mean simply that the fish are eating 75 times as much food. The seasonal fluctuations result from the interaction of all of the factors mentioned above which influence the accumulation of radioactive materials. As the feeding rate increases for each organism, its intake of radioisotopes may be disproportionately large. The consumer is not only eating more grams of food, but each food organism has become more radioactive, and the effective time intervals between trophic levels have become less. Possibly the food habits of the species in question have also changed. A complete evaluation of the seasonal fluctuations in any one species would require an immense amount of work, not only on the food habits of the species but also on its physiology and on the radioactive contamination of its food organisms.

Not all seasonal variations are associated merely with temperature since deviations may occur where complex life cycles are involved. This occurs in immature insects which are less radioactive during quiescent periods than when the larvae or nymphs are feeding. It is also true of salmon that return to the Columbia River to spawn. The adult salmon virtually stop feeding when they enter fresh water, and consequently pick up very little radioactive material. Krumholz (1956) also observed definite seasonal changes in the accumulation of radiomaterials by fish of White Oak Lake. These corresponded to some extent with seasonal changes in temperature. He noted, however, that the accumulation of radioisotopes in black crappie and bluegills stopped at the first of August when the temperature reached about 80° F. He attributes the rapid loss of radioactive materials during August and September to a period of summer dormancy for these species.

SUMMARY

Some radioactive materials introduced into aquatic environments may be accumulated by the organisms. The amount of accumulation will vary over many orders of magnitude depending upon the kinds of isotopes involved and many physical, chemical, and biological factors. Such concentration is of considerable importance in the control of radiological hazards and the aquatic biologist has definite responsibilities in this area.

The processes of adsorption and absorption are of major importance in the uptake of radioisotopes by plants but appear to be of less importance than the food chain in the uptake by aquatic animals. The concentration of radioactive substances will vary between species and tissues and will fluctuate according to food habits, life cycles, and seasonal changes.

Within the biotic mass, a major fraction of most radioactive contaminants will be held by the organisms which make up the primary trophic levels. In a flowing stream, the specific activity of a radioisotope will diminish along the food chain. Where the turnover rates of certain isotopes can be measured, inferences can be drawn on feeding habits.

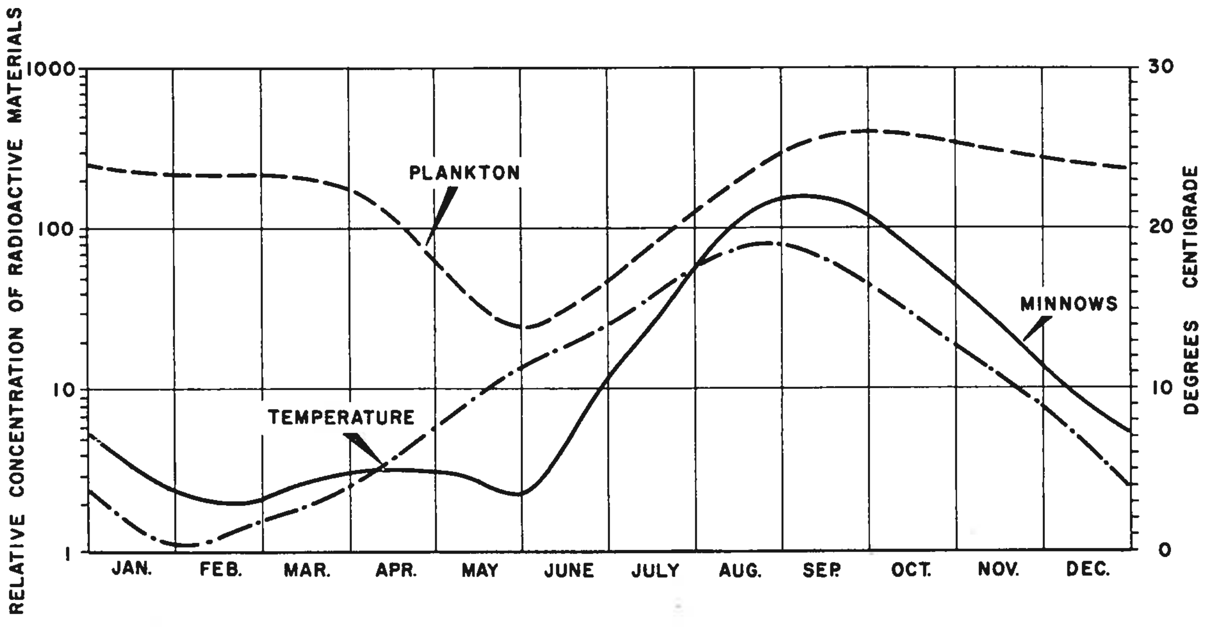

Figure 5 - Seasonal fluctuations in radioactivity of Columbia River organisms.

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Chapter II

RELATIONSHIP TO POLLUTION OF PLANKTON

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ECOLOGY OF PLANT SAPROBIA

R. Kolkwitz and M. Marrson

The present report contains a listing of approximately 300 plant organisms of importance for the self-purifying capacity of our native waters. In order to express their dependence on decomposing organic nutrients, we introduced in 1902 (1) the term "saprobia" for them and subdivided them into poly-, meso- and oligosaprobia in accordance with the increasing degree of mineralization in such waters.

Such a classification presupposes that the respective organisms are uniquely dependent, within relatively narrow limits, on the chemical composition of the water for their distribution and development in situ. The Institute mentioned has available a very large number of analyses of the composition of a great many different bodies and courses of water and many years of investigation have shown that this assumption is valid if we take into account in such a classification an ecology which assigns a higher value to the occurrence of floristic constituents -- insofar as these develop typically -- than the determination of merely isolated specimens. The present case therefore concerns a classification of aquatic plants on a chemo-physiological basis in which laboratory tests are less decisive than the findings in situ of their presence. Such locations are collectors or channels for raw putrescible sewage, filtered effluents from trickle fields or biological oxidation, settling or collecting tanks absorbing nutrient-containing inflow as well as overgrown ponds, cisterns and dry wells.

For reasons of lack of space, we have temporarily omitted from consideration the organisms of pure water (catharobia), specifically their plankton and also because the term saprobia is hardly applicable to them as in the case of a number of algae from pure mountain streams and lakes. Here we should point out that our present observations indicate that there are very few chlorophyll-containing organisms which refuse any organic nutriment under natural conditions and that there are hardly any surface waters which do not react to permanganate through their content of organic substances.

The already mentioned extensive and definitive influence of aquatic organisms, especially when microscopic, has already been utilized by Ferd. Cohn to a limited extent for the evaluation of the degree of purity of these waters as a function of the organisms existing in them. This method of biological analysis was therefore developed in the botanical field. With its further development must be credited Mez, Schorlein, Lindau, Schmidmann (by founding the Institute mentioned), Schiemenz and Hofer among many others.

The large-scale experiments most appropriate for testing the relation between organisms and the character of the water have steadily increased in Germany since 1870 by reason of the increased outflow from the sewers of the growing towns and cities and through the increased volume of sewage from industrial agricultural enterprises. Obviously, methods of purification have been perfected at the same time which have also lead to valuable and pertinent experimental findings. In spite of certain differences in chemical composition, all these effluents produce the same biological picture in general in the collectors because a stream or lake tends to compensate the existing differences by dilution, neutralization, oxidation, etc. and thus creates the same similar nutritive conditions for saprobia.

A detailed discussion of the considerations in classifying the organisms contained in the attached list into the respective zones will follow in the Reports of the Institute, together with a discussion of the respective animals and with the addition of illustrations. In this report here, we assume familiarity with all the organisms listed as well as the knowledge of their general habitat within the three typical regions of bank, bottom (benthos) and open water (plankton) and limit ourselves to giving a brief characteristic of the three different zones.

I - The zone of polysaprobia is characterized from the biological viewpoint principally through the wealth of schizomycetes by number, species and variety. Polysaprobia may gradually overlap into the zone of mesosaprobia (cf. Spherotilus) but will never occur grouped in the oligosaprobiotic zone but only in isolation and then generally erratically. The overlapping of Spherothilus into the second zone finds its reason in the fact that Spherotilus is an inhabitant of running water and needs aeration in addition to motion.

Designations such as "in pure and impure water" or "Euglena viridis is found in all Euglenaceae habitats" are offenses against the ecological viewpoint in our system. The number of germs capable of development per cubic centimeter of standard nutrient gelatine can easily rise above 1 million. Our standard food fishes can become easily subject to asphyxiation in this zone.

From the chemical viewpoint, the zone of the polysaprobia is characterized by the predominance of reduction and cleavage processes, through absence or low content of oxygen, through an abundance of carbondioxide and a relatively high content of nitrogenous and putrescible nutrient substances. The mud of this zone is frequently rich in ferrous sulphide.

We have no large streams of polysaprobiotic character over any great distance; even the river "Wupper" is not polysaprobiotic.

II - In the zone of the mesosaprobia, we distinguish sections with strong and/or weak mesosaprobiotic character. In the former of the two, self-purification seems to take place more aggressively than in the latter.

From the biological viewpoint, the first part of this zone is characterized by the predominance of Schizophyceae and -- especially in moving water -- by a more or less great abundance of Eumecytes; Peridiniales are practically completely absent. Animal life may be rather fully developed and thus may attract fishes for feeding. The fishes are here subject to asphyxiation only infrequently. The numerical content of bacteria per cubic centimeter is still high and may run into hundreds of thousands.

Good examples for this formation are furnished in particular by contaminated ponds and ditches, expecially of trickle fields.

In contrast to the symbioses described so far and in special consideration of the benthonic diatoms, we might designate the second part of the mesosaprobiotic zone as the formation of the Bacillariaceae, especially if we consider the dearth of varieties in the strong mesosaprobiotic zone. In addition to the diatoms, we find here in general, however, a rather wide classification of the vegetation, e.g., among the Chlorophyceae, so that on the whole given types do not necessarily predominate.

The number of bacteria developing on standard nutritive gelatine normally amounts to less than 100,000.

All mesosaprobia are resistant to a minor affluence of sewage. Many of the higher aquatic plants find, particularly beyond the weak mesosaprobiotic zone, adequate and often rather favorable conditions of vegtation. The progressive course of self-purification is as characteristic from the chemical as from the biological viewpoint. Aeration and production of oxygen through assimilation of carbon have made possible the inception of oxidation processes which favor the life of the coarser fauna as already mentioned. Especially in the strong mesosaprobiotic part, the oxygen content tends to decrease, however, in darkness or with a clouded sky but rises again and often beyond the saturation maximum under increased light.

Such decomposition products of protein as asparagin, leucine, and glycine (all characterized by NH_4- and CCOH-groups, i.e., decomposition and oxidation stages) appear to be widely present in this zone (but in great dilution which makes their demonstration rather difficult) as well as ammonia salts and -- when approaching the oligosaprobiotic formation -- nitrites and nitrates, the oxidation stages of ammonia.

When stored in flasks, normal water from this zone does not tend to putrefy but may form a minor supernatant layer under certain circumstances.

Normal effluent from the trickle fields which may be designated -- at least during the hot season -- as typically nitrous water should probably be counted in the weak mesosaprobiotic region.

III - The zone of the oligosaprobia is characterized by the termination of mineralization and all aggressive processes of self-purification are normally absent here. The biological organization is manifold. If they exist, Peridiniales reach typical development in a few representatives. Sensitive to sewage, Charales now begin to show themselves but polysaprobia are absent even in small amounts. The number of bacteria developing on standard nutritive gelatine usually is less than 1,000 per ccm unless erratic forms have been infused. The dearth of planktonic Schizomycetes is also characteristic. Given benthonic forms of this class may occur, however, typically in the organic matting of the banks.

Chemical analysis of the waters from this zone shows us that the consumption of permaganate is relatively low and that we find only traces of organic nitrogen. Determined in a suitable manner, the consumption of oxygen is minor. Measured by immersing a white disk, the transparency of the water is generally high in calm weather. The mud from this region is generally poor in reduction processes but may assume a mesosaprobiotic character. In general, mud that can be characterized as oligosaprobiotic, will probably not be widely distributed.

Since the rapid decomposition of organic substances no longer dominates the chemistry of this region, less obviously effective substances may have an influence on ecological composition, e.g., such minerals as determine the differing hardness of the waters. However, there do not exist as yet any complete observations on this, not even for Phanerogamia.

The waters of all the above zones nearly all show an alkaline reaction; those with an acid reaction we intend to describe similar to the above at some later time.

We intend to publish elsewhere the "Ecology of Animal Saprobia" which is in harmony with our system.

PHYSIOLOGICAL SYSTEM OF PLANT SAPROBIA

Within the individual zones, the organisms are arranged in accordance with the Engler System, except for some deviations in the flagellate group. The following listing is based only on our own observations from nature. Such organisms as we did not ourselves observe at the main source of their development, have not been taken into account even if pertinent notes on them existed in literature; those have been omitted also which have no biocenotic value for the present purposes on the basis of our present experience (e.g., Bacterium cellulosae Omelianski Mig., many pantotrophic bactteria and various phanerogamia).

Doubts on the exact place of classification of some of the organisms were resolved by allocating them to the less nutrient of the respective zones.

I. Polysaprobia

Schizomycetes
- Spirillum tenue Ehrbg.
- " serpens (O. F. Müller).
- " Rugula (O.F. Müller).
- " Undula Ehrbg.
- " volutans Ehrbg.
- Sphaerotilus natans Ktz. } cf. Mesosaprobia
- " roseus Zopf }
- Zoogloea ramigera Itzigsohn.
- Streptococcus margaritaceus Schröter.
- Sarcina paludosa Schröter
- Beggiatoa alba (Vaucher) Trevisan
- " leptomitiformis (Mengh.) Trevisan.
- " arachnoidea (Ag.) Rabenhorst.
- Thiopolycoccus ruber Win.
- Chromatium okenii (Ehrbg.) Perty. } cf. Mesosaprobia
- " vinosum (Ehrbg.) Win. }
- " minutissimum Win. }
- Lamprocystis roseo-persicina (Ktz.) Schröter. }

Schizophyceae
- Arthrospira jenneri Stitz., when associated with Beggiatoa. cf. Mesosaprobia.

Euglenales
- Euglena viridis (Schrank)Ehrenbg., when abundant.

Protococcales
- Polytoma uvella Ehrbg.

II. Mesosaprobia

1. Strong Mesosaprobiotic

Schizomycetes
- Sphaerotilus natans Ktz. } when associated with mesosaprobiotic Bacillariaceae and when in part with Cladothrix-like ramification. cf. Polysaprobia.
- " roseus Zopf }
- Thiothrix nivea (Rabenhorst) Win.
- Chromatium okenii (Ehrbg.) Perty } when associated with mesosaprobiotic algae. cf. Polysaprobia.
- Lamprocystis roseo-persicina (Ktz.) Schröter }
- Thiospirillum sanguineum (Ehrbg.) Win.
- Spirochaete plicatilis Ehrbg., is classed by us as animal.

Schizophyceae
- Oscillatoria princeps Vaucher
- " tenuis Ag.
- " chalybea Mertens.
- " putrida Schmidle.
- " chlorina Kutz
- " splendida Grev.
- " brevis Ktz.
- " formosa Bory.
- Arthrospira jenneri Stitz. cf. Polysaprobia.
- Phormidium uncinatum (Ag.) Gomont.
- " autumnal (Ag.) Gomont.
- " foveolarum (Mont.) Gom.

Cryptomonadales
- Cryptomonas nordstedtii (Hansg.) Senn; probably = Cryptoglena coerulescens Ehrbg.

Euglenales
- Euglena viridis var. lacustris Francé.
- Lepocinclis ovum Ehrbg.
- " texta (Dug.) Lemm.
- Cryptoglena pigra Ehrbg.

Bacillariales
- Hantzschia amphioxys (Ehrbg.) Grun.
- Nitzschia palea (Kutz.) W. Sm. and their variety fonticola Grun.
- Stauroneis acuta W. Sm.

Protococcales
- Chlamydomonas de baryana Gorosch.
- Spondylomorum quaternarium Ehrbg.
- Stichococcus bacillaris Naeg F. confervoidea Hazen. cf. weak mesosaprobia.
- Chlorella infusionum (Beyerk.).

Confervales
- Ulothrix subtilis Kuetz. forma.
- Stigeoclonium tenue Ktz. (delimitation of variety difficult) attenuates toward weak mesosaprobiotic zone.

Phycomycetes
- Mucor, and Zygorhynchus group.
- Apodya lactea (Ag.) Cornu - Leptomitus lacteus Ag.

Hemiascomycetes
- Endoblastoderma salmonicolor Fischer & Brebeck and some Torula which probably belong here.

Euascomycetes
- Fusarium aquaeductuum Lagerheim.

2. Weak mesosaprobiotic

Schizomycetes
- Lampropedia hyalina (Ehrbg.) Schröter.
- Cladothrix dichotoma Cohn.

Schizophyceae
- Oscillatoria limosa Ag.
- " antliaria Jurgens
- Phormidium subfuscum Ktz.
- Aphanizomenon flos aquae Ralfs.

Chrysomonadales
- Chrysosphaerella longispina Lauterb
- Synura uvella Ehrbg., when associated with Closterium acerosum, Brachionus, Rotifer, actinurns and isolated specimens of Euglena viridis. cf. Oligosaprobia

Cryptomonadales
Cryptomonas crosa Ehrbg.
" ovata "

Euglenales
Euglena acus Ehrbg.
" spirogyra Ehrbg.
" oxyuris Schmarda.
" deses Ehrbg.
" pisciformis Klebs
" quartana Moroff.
" tripteris (Duj.) Kl.
" velata Klebs.
Phacus caudata Hübner.
Trachelomonas hispida Stein.
" volvocina Ehrbg.
Colacium vesiculosum (Ehrbg.) Stein

Peridiniales
Ceratium tetraceros Schrank, occurs also associated with Lamprocystis, Chromatium okenii.

Bacillariales
Melosira varians Ag. (preferred mineralized organic substance).
Stephanodiscus hantzschianus Grun
" " var. pusillus Grun.
Diatoma vulgare Bory.
Synedra Ulna var. splendens (Ktz.) J. Brun.
" actinastroides Lem.
" radians (Ktz.) Grun.
" vaucheriae Ktz.
Microneis minutissima (Ktz.) Cleve.
Navicula brebissonii Ktz.
" radiosa Ktz.
" cryptocephala Ktz.
" rhynchocephala Ktz.
" cuspidata Ktz.
" mesolepta Ehrbg.
" amphisbaena Bory.
" ambigua Ehbg.
" atomus Naeg.
Stauroneis phoenicenteron Ehrbg.
Gomphonema tenellum W. Sm.
" olivaceum Ktz.
" parvulum Ktz.
Rhoicosphenia curvata (Ktz.) Grun.
Nitzschia parvula W. Sm.
" communis Rabh.
" stagnorum Rabh.
" dissipata (Ktz.) Grun.
" acicularis (Rabh). W. Sm.
Surirella ovalis Breb. var. ovata = S. ovata Ktz., also var. minuta and angusta.

Conjugatae
Closterium acerosum Ehrbg.
" parvulum Naeg.
" moniliferum Ehrbg.
" leibleini Ktz.
Cosmarium botrytis Menegh.
Spirogyra crassa Ktz.
" porticalis (Vauch.) Cleve.

Protococcales
Carteria cordiformis Dill.
Chlamydomonas ehrenbergi Gorosch.
" brauni Gorosch.
" reinhardi Dang.
" kuteinikowi Gorosch.
" reticulata Gorosch.
Chlorogonium euchlorum Ehrbg.
Gonium sociale (Dng.) Warm. = Gonium tetras A. Br.
Stichococcus bacillaris Naeg; cf. strong Mesosaprobia.
Chlorococcum botryoides Rabh.
Pediastrum boryanum (Turp.) Menegh., especially when numerous young specimens exist.
Rhaphidium polymorphum var. aciculare (A.B.) Rab.
Scenedesumus auadricauda (Turp.) Bréb.
" acuminatus (Lagh.) Chodat.
" obliquus (Turp.) Ktz.
" bijugatus (Turp.) Ktz.
} especially when numerous young specimens exist.
Selenastrum bibraianum Reinsch.
Dictyosphaerium pulchellum Wood.
" ehrenbergianum Naeg.
Chlorosphaera limicola Beyrk.

Confervales
Ulothrix subtilis (Ktz.); cf. Oligosaprobia.
Conferva bombycina (Ag.) Wille.
Microthamnion kuetzingianum Naeg.
Oedogonium species.
Cladophora crispata Ktz.
Vaucheria sessilis (Vauch.) D.C.

Florideae
Hildebrandia rivularis (Liebm.) Bréb.

Monocotyledoneae
Holodea (Elodea) canadensis R. & Mchx.
Lemna minor L.
" polyrhiza L.

Dicotyledoneae
Ceratophyllum demersum L., when in certain forms of growth.

III. Oligosaprobia

Schizomycetes
Chlamydothrix ochracea (Ktz.) Mig.
Gallionella ferruginea Ehrbg.
Crenothrix polyspora Cohn.
Clonthrix fusca Roze.

Schizophyceae
Dactylococcopsis rhaphidioides Hansg.
Coelosphaerium kuetzingianum Naeg.
Gomphosphaeria lacustris Chodat.
Microsystis incerta Lemm.
Clathrocystis aeruginosa (Ktz.), Henfrey and other Microcystis-varieties.
Merismopedia glauca (Ehrbg.) Naeg.
" convoluta Bréb.
Oscillatoria anguina Bory.
" rubescens D. C.
" agardhii Gom.
Phormidium inundatum Ktz.
" papyraceum (Ag.) Gom.
Microcoleus subtorulosus (Bréb.) Gom.

Anabaena flos aquae (Lyngb.) Bréb.
" spiroides Kleb.
Glaucothrix gracillima Zopf.
Calothrix parietina (Naeg.) Thuret.

Chrysomonadales
Chromulina rosanoffii Woron.
Mallomonas acaroides Perty.
" producta (Zach.) Iwanoff.
Synura uvella Ehrbg.; cf. mesosaprobia.
Uroglena volvox Ehrbg.
Dinobryon species.

Euglenales
Euglena oblonga Schmitz.
" geniculata (Duj.) Schmitz.
" minima Francé.
Phacus longicauda (Ehrbg.) Duj.
" pleuronectes Nitzsch.
" parvula Klebs.
" pyrum (Ehrbg.) St.

Peridiniales
Gymnodinium palustre Schilling.
Ceratium hirundinella O.F. Müll.
Peridinium minimum Schilling.
" quadridens Stein.
" cinctum Ehrbg.
" tabulatum Clap. & Lachm.
" berolinense Lemm.
" bipes Stein.
Gonyaulax apiculata (Pen.) Entz.

Bacillariales
Melosira ambigua O. Müll.
" granulata (Ehrbg.) Ralfs.
" italica Ktz.
" binderiana Ktz.
" crenulata Ktz.
" arenaria Moore and other species
Cyclotella meneghiniana Ktz.
" kuetzingiana Thw.
" comta (Ehrbg.) Ktz.
Tabellaria flocculosa (Roth) Ktz.
Meridion circulare Ag.
Fragilaria virescens Rulfs.
" construens (Ehrbg.) Grun.
" mutabilis (W. Sm.) Grun.
Asterionella formosa Hass.
Synedra acus Ktz.
Syedra ulna (Nitzsch) Ehrbg. and varieties
Eunotia arcus (Ehrbg.) Rabh.
Achnanthes exilis Ktz.
Navicula mesolepta Ehrbg.
" viridis Ktz.
" maior Ktz.
" gibba Ehrbg.
" dicephala W. Sm.
" inflata Ktz.
" iridis Ehrbg.
" limosa Ktz.
" gastrum Ehrbg.
" hungarica Grun.
" perpusilla Grun.
" viridula Ktz.
" clausii Gr.
Pleurosigma attenuatum (Ktz.) W. Sm.

Gomphonema acuminatum Ehrbg.
" capitatum Ehrbg.
" constrictum Ehrbg.
" angustatum Ktz.
Cymbella ehrenbergii Ktz.
" cistula (Hempr.) Kirchn.
" lanceolata (Ehrbg.) Kirchn.
Encyonema prostratum Ralfs.
" ventricosum Ktz.
Amphora ovalis Ktz.
Epithemia turgida (Ehrbg.) Ktz.
" sorex Ktz.
" zebra (Ehrbg.) Ktz.
Rhopalodia gibba (Ktz.) O. Müller
Bacillaria paradoxa Gmelin
Nitzschia sigmoidea (Ehrbg.) W. Sm.
" linearis (Ag.) W. Sm.
" vermicularis (Ktz.) Grun.
" vitrea Norman.
Cymatopleura elliptica (Bréb) W. Sm.
" solea (Bréb) W. Sm.
Surirella biseriata Bréb.
" splendida Ktz.

Conjugatae
Closterium lunula Ehrbg.
" dinanae Ehrbg.
" ehrenbergii Menegh.
" areolatum Wood.
Staurastrum tetracerum Ralfs.
Spirogyra irregularis Naeg.
" nitida (Dillw.) Linck.
" gracilis Ktz.
Mougeotia genuflexa (Dillw.) Ag.

Protococcales
Chlamydomonas angulosa Dill.
" intermedia Chod.
" longistigma Dill.
" pisiformis Dill.
" variabilis Dang.
Eudorina elegans Ehrbg.
Pandorina morum Bory.
Volvox globator L.
Carteria obtusa Dill.
Lobomonas francei Danj.
Pteromonas alata (Cohn) Seligo
Phacotus lenticularis Stein.
Tetraspora gelatinosa (Vauch.) Desv.
" explanata Ag.
Dimorphococcus lunatus A. Br.
Rhaphidium polymorphum Ktz.; parallel to Mesosaprobia.
Richteriella botryoides (Schmidle) Lemm.
Protococcus botryoides (Ktz.) Kirchn.
Pediastrum duplex Meyen.
" kawraiskyi Schmidle.
" tetras (Ehb.) Ralfs.
" Rotula (Ehb.) A. Br.
Actinastrum hantzschii Lagerh.
Coelastrum microporum Naeg.
" reticulatum (Dang.) Senn.
Sphaerocystis schroeteri Chod.
Hydrodictyon utriculatum (L.) Lagerh.
Botryococcus braunii Ktz.

Confervales

Ulothrix variabilis Ktz.
" subtilis var. variabilis (Ktz.) Kirchn.; cf. Mesosaprobia.
" zonata (Web. & Mohn) Ktz.
Draparnaldia glomerata (Vauch.) Ag.
" plumosa (Vauch.) Ag.
Chaetophora elegans (Roth) Ag.
Bulbochaete setigera Ag.
Coleochaete pulvinata A. Br.
Rhizoclonium hieroglyphieum (Ag.) Ktz.
Cladophora glomerata Ktz.
Vaucheria species.

Florideae
Lemanea torulosa (C. Ag.) Sirodot
Batrachospermum moniliforme Roth.

Bryophyta
Fontinalis antipyretica L.
Amblystegium riparium Schimp.

Pteridophyta
Salvinia natans All.
Isōetes lacustris L.

Monocotyledoneae
Potamogeton pectinatus L.
" crispus L.
Lemna trisulca L.

Dicotyledoneae
Nuphar lutenum Sm.
Nymphaea alba L., particularly the former is resistant to a great volume of sewage but does not indicate it.

In addition to the Oligosaprobia listed here, there are many others but these are less important for the evaluation of water.

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EFFECT OF SUNLIGHT AND GREEN ORGANISMS* ON RE-AERATION OF STREAMS

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The diurnal changes of dissolved oxygen in running streams were studied. The oxygen increased rapidly during the morning hours, reaching a maximum in the afternoon and a minimum at the early morning hours just before sunrise. The variations were similar in a tidal section of the Delaware, but were somewhat affected by the changes in tides.

Laboratory experiments with river water containing green algae showed that small temperature changes had practically no effect, the dissolved oxygen increasing or decreasing depending upon light and darkness. Direct sunlight was not an important factor, because increases were equally great with diffused light and with direct sunlight. The dissolved oxygen in water containing large quantities of blue-green and green algae could be decreased from supersaturation to 17 per cent saturation by placing the water in darkness, and could also be increased to 282 per cent saturation by subjecting it to diffused light. Changes in pH values followed changes in oxygen saturation. Under similar conditions the oxygen dissolved could be decreased by

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half when the number of organisms was decreased by half. Sampling during the afternoon of polluted rivers containing green organisms leads to erroneous results. In stream-pollution surveys all factors must be taken into consideration.

Organisms containing the green pigment chlorophyll are capable of synthesizing complex organic compounds from carbon dioxide and water and giving off oxygen. This process, photosynthesis, takes place only in the presence of light. The first product of the process is presumably formaldehyde, from the condensation of which sugars and starches are formed. Aquatic plants capable of synthesizing their own food in this manner, and encountered in the streams, are mostly algae.

Some of the factors that influence photosynthesis are light intensity, temperature, partial pressure of carbon dioxide, and aeration. Light, especially the ultra-violet rays, stimulates the growth and activities of the green and blue-green algae. In turbid waters the penetration of light is reduced and hence photosynthesis is reduced. On the other hand, in a clear stream penetration of light is much greater and photosynthesis can take place at considerable depths.

The presence of carbon dioxide is also essential for photosynthesis. This may be replenished from the air or from the carbon dioxide produced as a result of respiration and bacterial activity. In the absence of free carbon dioxide plants may utilize the bicarbonates.

If conditions are favorable for photosynthesis, the oxygen content of the water will increase sometimes far beyond saturation. During the dark hours oxygen is consumed and carbon dioxide given off. During daylight the process is reversed. Actually during the day, then the oxygen concentration in a stream is the balance between these two processes -- the rate at which oxygen is liberated by the activities of green organisms and the rate at which it is consumed by respiration and oxidation. During the night, however, there will not be any liberation of oxygen, but the consumption will go on unabated with the result that the oxygen saturation will be lower. If the pollution in a stream is relatively great, the consumption of oxygen will overbalance its production and there will be depletion of oxygen. If, on the other hand, the pollution is slight, there may be a supersaturation of oxygen.

The green algae are most abundant in water during the summer. Their development follows the curve of the temperature of water, and maximum growth occurs in July and August. The optimum temperature for their growth is between 15° and 25° C., although some species can tolerate extreme heat or cold. The blue-green algae are also abundant during the summer months, although their maximum growth often occurs a little later in the season and some of them can tolerate somewhat higher temperatures than the green algae.

Although these changes in algal growth and the subsequent changes in dissolved gases in the water have been known for a long time, actual observations and determinations of diurnal changes in running streams have been reported only in a few instances. An observation made on the Illinois River (1909) was reported without much comment. Butcher, Pentilow, and Woodley (2) have given detailed studies on two polluted rivers in England. The studies by Birge and Juday (1) on the inland lakes of Wisconsin, although dealing with the changes taking place, were not concerned with running river water. Duvaux (4) and Duval and Dumarand (3) have discussed the mechanism and the rate of reaction changes in connection with the gaseous exchange of submerged aquatic plants. Moore (5) has published some observations on certain marine organisms in reaction to light, and Saunders (6) has published a note on photosynthesis and hydrogen-ion concentration. Several other investigators have dealt more remotely with the subject in hand, but none made an attempt to correlate the changes observed in the laboratory with actual conditions in streams.

It was with the purpose of evaluating the role of these green organisms in the re-aeration of the Delaware, Connecticut, and Raritan rivers that these studies were undertaken, but only some results obtained with the Delaware River water are here presented.

METHODS

Data obtained by sampling the river at definite places for 24-hour periods included temperature, dissolved oxygen, biochemical oxygen demand, and B. coli. Samples were taken in the middle and two quarter points of the river at mid depth. For the laboratory experiments large samples were obtained from different points in the Delaware River. Some samples were exposed to light or kept in the dark in open containers with uniform depth. Others were distributed into glass-stoppered bottles, which were immersed in a water bath and the temperature regulated with hot and cold water. At frequent intervals (1 to 1-1/2 hours) the temperature and dissolved oxygen content were determined. All transfers of the water were made by a siphon immersed under water to avoid bubbles. Analyses were made to complete 24-hour cycles; time is given as Eastern Standard Time. Analyses made according to the standard A.P.H.A. methods.

EFFECT OF SUNLIGHT ON RUNNING STREAMS

The dissolved oxygen determinations obtained in the tidal section of the Delaware River below Trenton, N. J., are given in Figure 1. The dissolved oxygen increased rapidly during the morning hours, with a maximum between noon and 4 p.m. During this period the tide was outgoing, so that the pollution, which is discharged by Trenton and the cities below, had no effect. With the turn of the tide the dissolved oxygen decreased rapidly during the next few hours, with the decrease slowing up when the maximum flood tide approached. During daylight hours the dissolved oxygen increased rapidly with outgoing tide, but during the night with outgoing tide it decreased still further until the lowest was reached at about 3 a.m. As daylight increased the dissolved oxygen increased. The temperature of the water was constant between 8 a.m. and 6 p.m., and in spite of the decrease in temperature the dissolved oxygen decreased rapidly during the night. This is contrary to the solubility of oxygen at

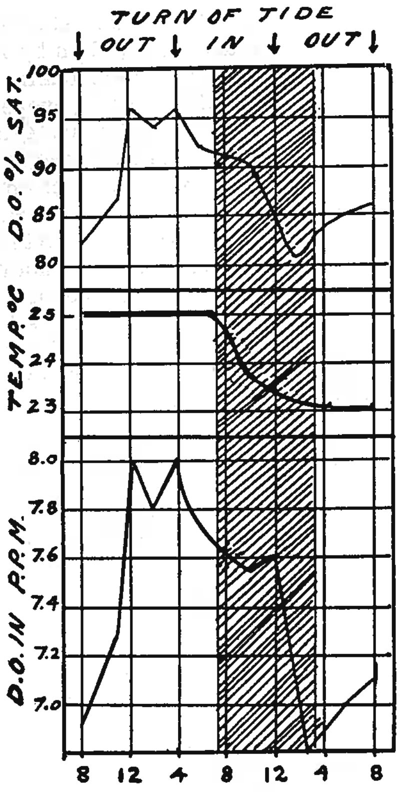

Figure 1 - Dissolved Oxygen in the Tidal Section of Delaware River.

different temperatures; an increase in dissolved oxygen rather than a decrease could be expected. These changes were not peculiar to the water in the tidal section. For example, the results obtained during daylight hours in the river about 50 miles above Trenton (the river is subject to tide up to Trenton) 2 days previous are given in Figure 2. The temperature fluctuation during the day was 1° C. The rapid increase in dissolved oxygen continued until a maximum was reached at 3 p.m. The increase and decrease in saturation occurred irrespective of any small temperature fluctuations. Similar results were obtained in a number of instances, which will be published elsewhere. This paper deals mainly with some of the factors which seem to be responsible for the fluctuations.

A set of results obtained with Delaware River water, brought to the laboratory, is given in Figure 3. The experiment was conducted on August 6, 1929, and the days following. The dissolved oxygen decreased gradually until 3:15 a.m., after which it began to rise slowly but did not reach the original value. The dissolved oxygen was practically constant during the afternoon with a constant temperature, decreased with a rapidly decreasing temperature, followed again by a slow rise in dissolved oxygen in spite of a further decrease in temperature. The decrease of dissolved oxygen at night, in spite of the decreasing temperature, was undoubtedly due to the consumption of oxygen by microorganisms in the process of respiration and decomposition. The rise in dissolved oxygen in the early morning hours before the action of light became effective was probably due to the further decrease in temperature, but the continued rise during the rest of the day must be due to the activities of the green organisms. In this case re-aeration was confined to the green organisms, since wind and rippling of the surface of the water were eliminated.

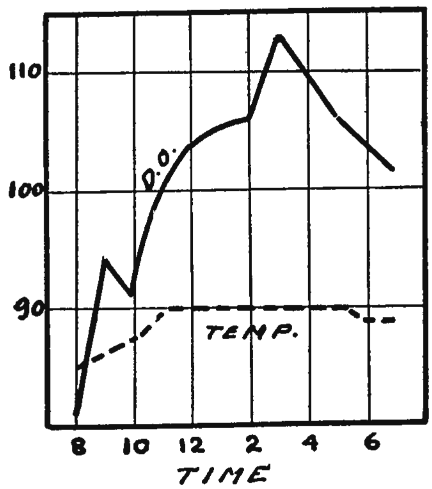

Figure 2 - Dissolved Oxygen during Daylight above Trenton, N. J.

The samples of water were kept in diffused light, and it was thought that the re-aeration due to the organisms might have been more intense if the water was kept in direct sunlight. The samples were exposed for 6 hours to direct sunlight and analyses made at intervals. An exposure of 1-1/2 hours increased the dissolved oxygen from 7.2 to 7.5 p.p.m., while the temperature increased from 20° to 24.5° C. No further increase in dissolved oxygen occurred, but the temperature of the water continued to rise so that the dissolved-oxygen saturation increased from 80 to 93 per cent. Thus the intensity of the light (direct sunlight with higher temperature as compared with light from an overcast sky) did not increase the degree of re-aeration, but hastened the time in which maximum oxygen production was possible.

Two other series of samples were subjected to light and darkness, while another series was kept in the dark. Those exposed to the light increased in dissolved oxygen while the temperature decreased; those kept in the dark decreased gradually in dissolved oxygen. The difference caused by the action of light amounted to 15 per cent.

Other samples were placed in stoppered glass bottles and submerged in water. In these instances no surface aeration could take place and the light had to penetrate not only a depth of 6 inches (15 cm.) of water but also the glass. The results are shown in Figure 4. An increase in dissolved oxygen took place until between 7 and 8 p.m., when a maximum was reached of 9.5 p.p.m. During the afternoon the saturation increased to 112 per cent, decreasing to about 100 per cent at 4:30 a.m. and again increasing to 118 per cent at 11 a.m. In these instances the oxygen liberated could not escape from the bottles, which accounts for the saturated condition even in the early morning hours. The water kept in the dark decreased from 8.4 to 7.5 p.p.m. in a straight line, while the saturation decreased from 101 to 90 per cent as compared with the increase to 118 per cent.

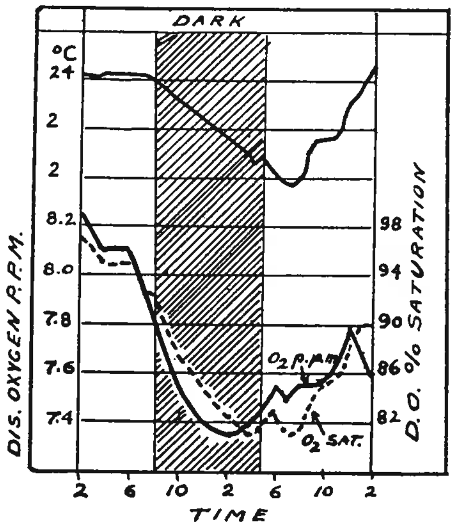

Figure 3 - Dissolved Oxygen in Delaware River Water as Tested in Laboratory.

Experiments made with distilled water to find out whether daily fluctuations took place when exposed to similar conditions in open beakers and stoppered bottles showed that the dissolved oxygen of the water did not increase in the dark and decreased slightly in the light.

The most abundant green organisms were Closterium, Pleurococcus, Eremosphora, Scenedesmus, Protococcus, Raphidium, and Botrycoccus. The number of algae were as high as 5200 per cc.

DIURNAL CHANGES IN WATER CONTAINING GREEN ALGAE

The diurnal changes in dissolved oxygen are similar from day to day, except that the dissolved oxygen may gradually increase. During the summer of 1930 laboratory experiments were conducted in an effort to determine the relation of the number of organisms to the chemical changes taking place.

Large samples of water, densely green with organisms, were collected from a creek tributary to the Delaware, receiving the effluent from some small sewage-disposal plants. The water was placed in carboys and subjected to alternating light and darkness for varying lengths of time.

The dissolved oxygen results of a part of the experiments, together with the changes in pH values, are given in Figure 5. The water when collected had a dissolved-oxygen content of 12.9 p.p.m. or a saturation of 154 per cent. After having been kept for 1 day in semi-darkness, the water was placed in an incubator for 18 hours, then placed in daylight for 10 hours, and so on. The dissolved oxygen dropped during the time the water was kept in semi-darkness from 12.9 to 2.2 p.p.m. and after having been placed in the incubator to

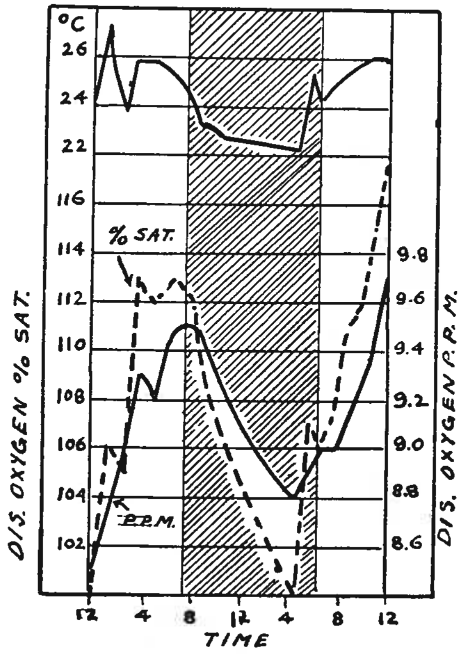

Figure 4 - Dissolved Oxygen in Samples Placed in Stoppered Bottles Submerged in Water.

1.2 p.p.m. During the next 7 daylight hours the dissolved oxygen increased to 14.7 p.p.m., decreased again during the night, and rose the following day to 21 p.p.m. Again during the next dark period it dropped to 10.9 p.p.m., from which it rose in 8 hours to 23.8 p.p.m. or a saturation of 282 per cent. The water was then subjected to a prolonged period of darkness of 63 hours, after which time the dissolved oxygen dropped to 3.2 p.p.m. During these periods the temperature was kept constant in the incubator at 21° C. As soon as the water was put back into daylight, the dissolved oxygen increased in 9 hours from 3.2 to 15.4 p.p.m.

The pH values fluctuated directly with the dissolved oxygen as may be seen from Figure 5. They rose by steps from 6.9 to 9.6+, while during the prolonged period of darkness this figure decreased to pH 7.1. The changes in carbon dioxide and carbonates were far less pronounced.

It is evident that the action of light has a cumulative effect, reaching under ordinary conditions its maximum at mid-day or thereafter. It seems to be more a time factor than merely an intensity effect, because the effects were the same when radiation was through glass or on cloudy days.

The numbers of blue-green and green organisms (photosynthetic) in the water were very high and mainly of the following species: Oscillatoria, diatoms (about six genera, particularly filamentous forms), Scenedesmus, and a few Microcytis, Pediastrum, and Desmids. Among the green flagellate protozoa Trachilomonas was most abundant. Most of the organisms were the blue-green Oscillatoria. The photosynthetic organisms slowly decreased during the 8 days of the experiment here reported -- namely, from 45,400 to 32,700 per cc. Bacterial eaters gradually increased.

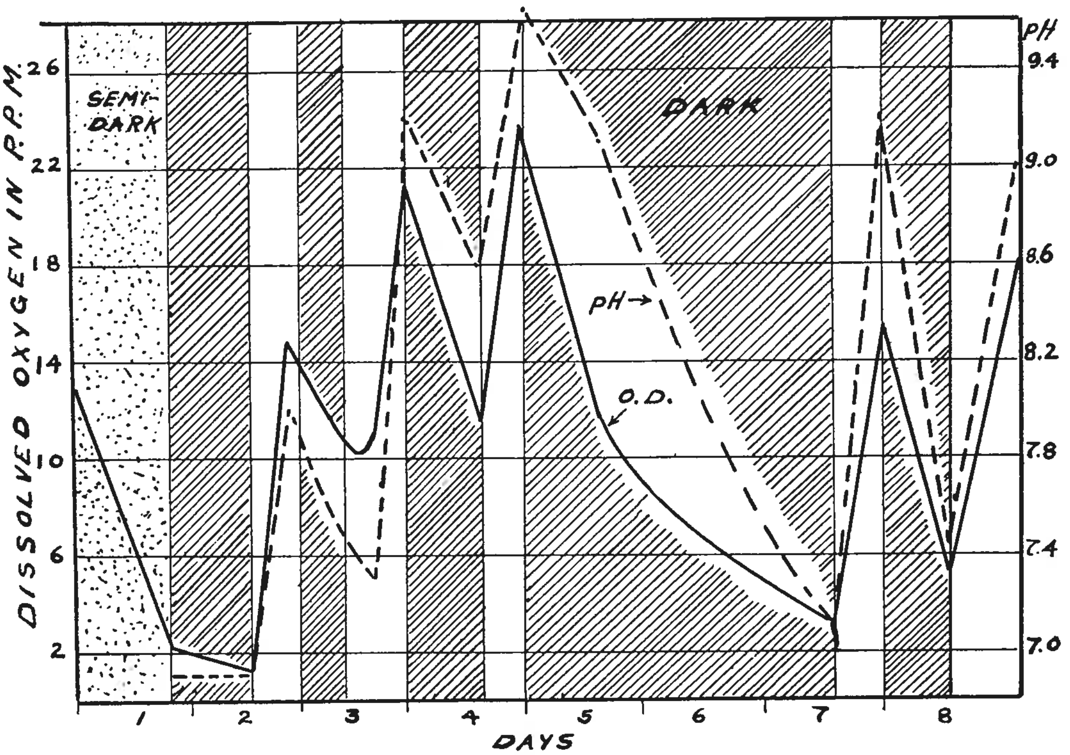

Figure 5 - Changes in Dissolved Oxygen and pH.

EFFECT OF CONCENTRATION OF ORGANISMS

The water with the large number of organisms was diluted by half with a mixture of river and tap water. The effect on the oxygen dissolved in the water was very pronounced, as may be seen from the following figures:

Time Days	Dissolved Oxygen Concentrated P.p.m.	Dissolved Oxygen Diluted P.p.m.
1	14.7	10.4
2	21.0	10.0
3	23.8	11.1
6	15.4	7.4

In the "diluted" water there were approximately half as many organisms as in the "concentrated" water, while the dissolved oxygen was also approximately half.

DISCUSSION

In dealing with the pollution of a stream the role of re-aeration by green organisms must be properly evaluated. If the pollution is not excessive so that the production of oxygen is overbalanced by the consumption, a marked increase in dissolved oxygen will result. With a more heavily polluted stream the dissolved oxygen might show from day to day, when samples are taken in the afternoon, complete saturation leading to erroneous conclusions because the temporary condition in the afternoon is by no means the daily average condition. Moreover, these erroneous results are usually obtained in the spring and especially in July and August with low stream-flow conditions and higher temperatures. From the reported and other results obtained it is believed that results for dissolved oxygen have been interpreted as meaning far more than was actually warranted. In stream-pollution surveys several more factors must be taken into consideration. From the high pH values obtained during the afternoons the deduction could have been made that either the water was alkaline or that large quantities of strongly alkaline trade wastes had been discharged.

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THE PLANKTON OF THE SANGAMON RIVER IN THE SUMMER OF 1929

Samuel Eddy

The Sangamon River, a small river in the central part of Illinois, has special interest to students of aquatic biology because it exhibits in a remarkable way the effects of the installation of a sewage treatment plant in alleviating pollution and at the same time the effects of the erection of a dam to impound water for municipal and industrial uses. The present study is an attempt to determine to what extent these effects are reflected by changes in the abundance of certain kinds of microscopic organisms, collectively called plankton, which live suspended in the water. As is well known, some kinds of plankton organisms, if present in sufficient numbers in reservoirs, may give disagreeable flavors to the water; other kinds may aid in the natural purification of polluted waters; and in streams and lakes generally plankton plays a role of more or less importance as food for larger organisms, including fishes. In our larger streams, such as the Rock River and the Illinois River, the plankton may be an important factor in fish production. In the Kaskaskia River, as an example of our smaller streams, the plankton is so scanty that it can have very little importance. The Sangamon River illustrates an intermediate stage in which the plankton is abundant enough to enter into the food chains of fishes to some extent but does not result in a yield of fishes appreciably greater than in the Kaskaskia. The writer's observations of plankton development in the upper part of the Sangamon from 1923 to 1929 were included in a general study on "Fresh-water Plankton Communities," submitted as a thesis in the Graduate School of the University of Illinois but not yet published. Further collections, made during the summer of 1929, showing the variety and abundance of organisms present at selected stations along the lower part of the river as well as the upper part, are reported in this paper.

The Sangamon River rises in McLean County and at first flows eastward into the northwestern part of Champaign County, where it turns southward and passes the villages of Foosland, Fisher, and Mahomet. It then flows in a general southwestward direction across Piatt County, passing Monticello, and across Macon County, passing Decatur. In Sangamon County, it receives its first large tributary, the South Fork, and passes Riverton and Springfield. It flows northward across Menard County, passing Petersburg. At its junction with Salt Creek it turns westward. It continues in a generally westward direction, forming the boundary between Mason County and Cass County, passing the village of Chandlerville, and finally emptying into the Illinois River about ten miles above Beardstown.

The length of the river is about 237 miles. The distance from the source to Decatur is about 103 miles, from Decatur to Springfield about 59 miles, and from Springfield to the mouth about 75 miles. The total drainage area is about 5,390 square miles, of which 1,940 square miles belong to Salt Creek, and 846 square miles belong to South Fork.

The current of the river at normal levels is never very great, since it flows through glacial till and occupies a well-worn valley. The river falls 120 feet in the first 10 miles and 300 feet in the balance of its course, or less than 2 feet per mile. The fall is far from regular, however, and there are many stretches where the gradient is very slight. The bottom is usually sand or fine silt, the latter predominating over most of the river.

Previous to 1923, no obstructions were encountered in the upper course of the river except several small ruined mill-dams. At Decatur a small dam raised the water level a few feet and held back a small supply for municipal purposes. Below this dam the city of Decatur discharged all its sewage, which usually was greater in volume than the water flowing over the dam. During times of low water, the sewage constituted the entire flow of the river below the dam, as all of the water above the dam was then diverted through the city water supply system. As a result of the pollution, the river below Decatur was devoid of normal aquatic life. Jewell (1920) reported no living organisms immediately below Decatur except those accustomed to conditions of pollution. Thirty miles below Decatur conditions were found to be improving, but even at Springfield, almost 60 miles downstream, the normal life was not completely restored. The writer was well acquainted with the river previous to 1920 and clearly remembers the extreme condition of pollution existing for at least 20 miles below Decatur. The bottom was covered with a thick layer of foul sludge, and the opaque water, which varied in color from inky black to milky white, depending on the season, contained large quantities of floating mouldy wastes.

At Springfield a second dam has obstructed the river for many years, raising the level of the water about six feet and forming a narrow pool that extends upstream several miles. Pollution below Springfield has been largely eliminated since the city's sewage treatment plant was put into operation, July 10, 1929. The wastes from Petersburg and Chandlerville are not sufficient to pollute the river to an appreciable extent.

In 1923 the city of Decatur, in order to increase its water supply, completed a large dam across the river just above the site of the old one, creating a lake one-half mile wide and 12 miles long. Later, in 1924, a sewage disposal plant was put into operation, handling one-third of the city wastes, and in 1928 the plant was enlarged to accommodate all the wastes. This relieved the extreme condition of pollution. The dredging of a new channel from Harristown for 20 miles downstream has aided by furnishing a new bed, free from the accumulated bottom sludge. These changes have resulted in a fairly clean stream, flowing through a lake-like reservoir in its upper region.

In the writer's previous study of the plankton of the upper river from 1923 to 1928, inclusive, weekly or semi-monthly collections were made from the river at Decatur and above. Very little plankton was found above Lake Decatur in those years. At Mahomet, about 50 miles from the source, no plankton forms occurred, though bottom organisms, especially diatoms and protozoans, occasionally appeared in the collections. The same was true at Monticello during the greater part of the year, but in mid-summer or early autumn, when the water was low, a scanty population of plankton organisms was found there. This was the first point in the course of the stream where plankton ever appeared. At Rhea's Bridge on the upper end of Lake Decatur, plankton was present in the water during most of the year but was never as abundant as at Lost Bridge, one mile above the dam, where many plankton species were abundant from March until December. During January and February the plankton of the lake was scanty and consisted chiefly of protozoans.

In 1929, trips were made in June, July, and September, for the purpose of collecting samples at intervals of about 20 miles over the entire river. The collections were made from bridges at or near Mahomet, Monticello, Lake Decatur, Harristown, Illiopolis, Riverton, Springfield, Petersburg, and Chandlerville. The method was to dip the water from mid-channel by lowering a ten-liter bucket on a rope. No stratification of plankton was noticed except at Lake Decatur, where the current was negligible and the plankton was much heavier near the surface. The principal collecting station on the lake was at Lost Bridge, and at this station a series of collections was made from bottom to surface and averaged. Each set of collections made at the other stations consisted of a 100-liter silk-net collection and a one-liter collection which was preserved with formalin and allowed to settle and then decanted in order to obtain the nannoplankton. The organisms were counted by the usual method in a Sedgwick-Rafter slide. All data were computed per cubic meter. The volume of the plankton in the silk-net collections was obtained by centrifuging for 3 minutes at 2000 revolutions per minute. The volume of the decanted plankton was not determined because of the large amount of silt present.

At the times of collecting, the river was 1-2 feet deep and 25-40 feet wide at Mahomet, the uppermost station, and 8-10 feet deep and 200-210 feet wide at Chandlerville, the lowermost station. The deepest portion from which collections were made was in Lake Decatur where the depth in the channel ranged from 10 to 18 feet. Below Decatur the river was quite shallow. It was 2-4 feet deep and 60-75 feet wide at the Harristown and Illiopolis bridges. At Riverton, after the union with the South Fork, the river was 4-6 feet deep and 100-114 feet wide. At the bridge north of Springfield the water (backed up by the dam) was 5-7 feet deep and 100-110 feet wide. At Petersburg the river was 100-150 feet wide and 7-10 feet deep in mid-channel.

The current, which was moderate at most places, was very slow in some stretches of the river and somewhat swifter in others with a greater fall. At Mahomet and Monticello, the current averaged about one-half mile per hour during the summer. In the main part of Lake Decatur no current could be detected. At Harristown and Illiopolis the current averaged about one mile per hour; at Riverton one-half mile per hour; and at Springfield just above the dam it was too slow to estimate. At Petersburg and Chandlerville it averaged a little more than one-half mile per hour.

The river level was slightly above normal when the plankton collections were made in June and July. The readings of the gage at the Decatur sewage disposal plant averaged 587.3 feet for June 25-27 and 587.6 feet for July 26-28. April and May were the highest months for the year 1929, the gage at the disposal plant reaching a maximum of 593.5 feet in those months. The lowest stage for the year was in September, although the gage readings on the dates of collections, September 10-12, averaging 584.0 feet, were not the lowest of the month. Thus the river was about 3-1/2 feet lower in September than it was when the June and July collections were made. The Decatur lake, however, did not fluctuate much, as the gage reading above the dam was 610.25 in June and July and 609.95 in September.

The temperature of the water at the time of collecting was about what would be expected under normal summer conditions. In June it ranged from 24° to 25° C. and in July from 25° to 28° C. No temperature data were obtained on the September trip, as the thermometer was broken in the field.

Hydrogen ion determinations were made at all stations and were found to run consistently about pH 7.6. This seemed normal for the river, as the readings agreed with those obtained by the writer in previous observations. On the upper river from 1923 to 1929, the readings in summer always ranged around pH 7.6, dropping to pH 7.0 or lower in winter.

Determinations of dissolved oxygen in the water at each station on the June trip were as follows: Mahomet 4.75 cc. per liter, Monticello 4.06, Decatur 4.62, Harristown 4.06, Illiopolis 4.62, Riverton 4.25, Petersburg 4.25, and Chandlerville 6.47. No determinations can be given for Springfield, as the June collections and data from that station were accidently lost. There was only a slight fluctuation in the amount of dissolved oxygen in the water at the various stations. At all points examined, the supply seemed sufficient for the support of abundant aquatic life.

A summary of the plankton collections is given in Table I, and the constituent organisms are listed in Tables II, III, and IV.

The general taxonomic composition of the plankton found in the river below Monticello was the same as that observed in most shallow lakes and larger streams of North America. Certain typical forms were conspicuous in their proper seasons, namely: two protozoans, Codonella cratera and Ceratium hirundinella; rotifers of the genera Brachionus, Synchaeta, Polyarthra, and Keratella; various cladocerans, particularly Moina affinis, Daphnia longispina, and Bosmina longirostris; and two copepods, Diaptomus siciloides and Cyclops bicuspidatus. A few bottom organisms, usually diatoms and protozoans, were often conspicuous in the plankton collections from the shallow portions of the river where the current could easily sweep them up from the bottom. They did not often appear in the collections from Lake Decatur but were quite common in the collections from the other stations, especially at Monticello, Harristown and Illiopolis.

The collections made in June showed no plankton at Mahomet and only a very scanty plankton at Monticello. The first heavy plankton occurred at Lost Bridge in Lake Decatur. Both the volume of the plankton and the number of species in the collections decreased downstream as far as Petersburg and Chandlerville, where the number of species increased slightly, though the volume of the plankton continued to decrease. Of the 50 species observed in the collections from the entire river in June, 36 appeared in Lake Decatur and 12 appeared farther downstream in relatively small numbers. Evidently a large amount of the downstream plankton owed its origin to the increase in Lake Decatur. Characteristic species which were most conspicuous in Lake Decatur and showed a decrease downstream were Difflugia lobostoma, Codonella cratera, Brachionus angularis, Polyarthra trigla, Keratella cochlearis, Moina affinis, Daphnia longispina, Bosmina longirostris, Cyclops bicuspidatus, and Lysigonium (Melosira) granulatum. Several other members of the plankton conspicuous in the lake did not appear at all below. The flagellates, Trachelomonas volvocina and Euglena viridis, decreased downstream to Petersburg and then started to increase. The only form that showed a decided increase below the lake was one of the algae, Actinastrum hantzschi.

The collections made in July showed that the plankton then had a distribution very similar to that of the preceding month. At Mahomet there was no plankton at all, and at Monticello it was very scanty. Of the 58 species found in the July collections, 47 first became abundant in Lake Decatur. Only 8 species occurred downstream which did not occur in the lake, and these were usually rare or inconspicuous, never forming an important part of the plankton. Many forms which were conspicuous in Lake Decatur showed a decided decrease below Decatur and apparently had their origin in the lake. Examples of these were the following: Pandorina morum, Pleodorina illinoisensis, Codonella cratera, Difflugia lobostoma, Trachelomonas ensifera, Euglena viridis, Ceratium hirundinella, Eudorina elegans, three species of the genus Brachionus and species of Filinia (Triarthra), Asplanchna, Polyarthra, Synchaeta, Pedalia, and Trichocerca (Rattulus), and Lysigonium (Melosira) granulatum. Only a few forms which decreased below Decatur showed a slight increase at Chandlerville. A peculiar feature was an increase in the number of Cyclops bicuspidatus, Keratella cochlearis, Diaphanosoma brachyurum, and Brachionus angularis at Harristown and Illiopolis. In general, the July plankton showed a decided decrease below Decatur. Just as in June, the lake apparently was acting as a reservoir, developing an abundant plankton which was then carried downstream and gradually thinned out in the lower river as the water was diluted by tributaries.

The September collections were made under somewhat different conditions from those in June and July, for the level of Lake Decatur was slightly below the crest of the dam, so that little or no water passed over, and the chief source of the water in the river below Decatur was the effluent from the city's sewage disposal plant. The current in the river was not as swift as at higher river levels, and under such conditions the larger tributaries, particularly the South Fork and Salt Creek, might be expected to add a small amount of plankton. While there still were no plankton organisms found at Mahomet, the plankton was more abundant at Monticello than previously. In Lake Decatur the collections were found to have a somewhat smaller volume and to include fewer species than previously. Downstream from the lake, however, many species, apparently originating in it, especially protozoans and algae, showed a steady increase in abundance; and several species additional to the lake list make their first appearance just below Decatur. Many conspicuous members of the plankton, particularly rotifers, appeared first at Riverton after the union with the South Fork and were abundant downstream from there. A decided increase in both abundance and species was noted at Springfield, which may in part be due to slack water above the dam. A further increase at Petersburg indicated that other conditions were favorable for greater plankton production.

Only a few species abundant in Lake Decatur showed a tendency to decrease rather than increase downstream. These were Difflugia lobostoma, Codonella cratera, Brachionus angularis, Keratella cochlearis, and some of the cladocerans and copepods. Of the 66 species found in the September collections, only 25 occurred in Lake Decatur, and 33 species occurred in the downstream collections which did not appear in the lake. Many of the latter showed a tendency to increase downstream. The increase was marked at Springfield and Petersburg, indicating that the lower river was maintaining a plankton population due in part to the low water stage and the reduction of the current. Such conditions in the river approach lake conditions, the waters remaining longer in the pool-like stretches. Since no water was then coming directly downstream from the lake, all the water in the river was effluent from the sewage disposal plant. Agersborg (1929) found this effluent to be teeming with annelids, rotifers, copepods, protozoans and algae, and states that these are organisms such as live in small ponds, though failing to mention any species which are typical of either clean-water or sewage plankton. It is doubtful if many, or any at all, of the lake forms survive passage through the sewage disposal plant, comprising as it does both sand filters, tanks and Dorr separators; and still more doubtful that there is any important development of additional plankton species until after the passage through the plant is completed.

Sphaerotilus natans, although very abundant in the sewage disposal plant, did not appear at any time in the collections. It is probable that the origin of many of the downstream plankton species at this period was in the quieter stretches of the river, which were seeded by the plankton originating in the lake at times when the water was passing over the dam.

The question often arises whether the plankton in a given part of a stream is developed there under local conditions or whether it is carried down from upstream. This survey indicates that, at times, part of the plankton, at least, is carried downstream. Wiebe (1928) and the Minnesota State Board of Health (1928) show that clean plankton from upstream is carried through polluted areas in the Mississippi below Minneapolis and St. Paul. In the Sangamon the downstream decrease observed in June and July may be due partly to the fact that local development was not sufficient to counterbalance the dilution from tributaries. In September, when the low stage of the water cut off the direct supply from the lake, local conditions downstream became more favorable for the development of plankton. When the current becomes very slow, the development of plankton becomes local and is governed by local conditions. If the current averaged one-half mile per hour, the time required for water to flow from the source to the mouth would be about 20 days. However, at normal stages the river has many pool-like stretches which retard part of the water, and rough estimates of the period of detention in the lake at Decatur range from two weeks to two months, depending on the river level. Thus the water remains in the lake at least twice as long as in the rest of the river. The water and the plankton it bears as it flows over the dam at Decatur will ordinarily be in the neighborhood of Chandlerville about a week later. In this way, at normal levels, there is a continual stream of water carrying plankton from the lake and passing downstream. Even though the downstream conditions are not favorable for plankton development, it seems possible for the water to retain part of the original plankton load for a week or more, so that a series of collections made at various points in the lower course of the river do not represent the development of plankton at each point but give glimpses of various stages of senescence as the plankton moves away from its source. It may be possible that the plankton observed downstream in September had originated from the lake when the water was still flowing over the dam, and that it was still progressing downstream. This, however, would hardly explain the origin of the plankton observed in the river immediately below Decatur.

No evidence of the former pollution was observed in the plankton of the Sangamon River. No pollutional organisms were found at Harristown, about eight miles below Decatur, where Jewell ten years earlier had found the plankton to be characterized by Sphaerotilus natans, nematodes, ciliates, and creeping rotifers, with desmids and phytoflagellates common when the water was high. In this area in 1929 the plankton was typical of clean water and was characterized by Codonella cratera, Polyarthra trigla, rotifers of the genus Brachionus, Cyclops bicuspidatus, cladocerans, and Lysigonium (Melosira) granulatum. Jewell found the dissolved oxygen usually low in that part of the river, especially during periods of low water. The determinations of dissolved oxygen made in 1929 showed an abundant supply. The sludge which was formerly so abundant had nearly disappeared, the water was clear, and a number of fishes were observed.

Very little is known regarding the former condition of the plankton below the polluted part of the river. Jewell's studies in 1918-1919, which extended only as far as Springfield, showed that the influence of pollution had partly ceased there and that a few typical clean-water plankton organisms were present in the river at that point. The abundant clean-water plankton now found in that part of the stream, including many more species than were reported by Jewell, indicates that the plankton population in the lower river is much greater than formerly, and this is due, no doubt, to the creation of the lake at Decatur and to the removal of the pollution barrier.

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TABLE I.

SUMMARY OF PLANKTON COLLECTIONS, SANGAMON RIVER, 1929.

Station	Volume (cc. per cubic meter)			Number of species represented		
	June 25-27	July 26-28	Sept. 10-12	June 25-27	July 26-28	Sept. 10-12
Monticello..........	.08	.08	.05	9	8	16
Lake Decatur.......	15.20	9.50	9.60	36	47	25
Harristown.........	6.00	8.00	10.00	22	34	27
Illiopolis............	9.00	8.00	8.40	23	31	26
Riverton............	3.00	3.90	3.60	17	35	35
Springfield..........	....	.80	12.60	..	28	36
Petersburg..........	2.20	.40	17.00	22	22	39
Chandlerville.......	.50	.30	6.00	24	22	30

TABLE II.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JUNE 25-27, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Petersburg	Chandler-ville
PROTOZOA							
Difflugia lobostoma Leidy	*86,820*	*100,000*	*86,658*	*60,000*	*25,000*	*22,000*	*20,000*
Trachelomonas ensifera Daday	*43,000*						*888,000*
Euglena sp.	*40,000*	*50,000*					*660,000*
Codonella cratera (Leidy)	*42,000*	*6,000,000*	*288,860*	*280,000*	*290,000*	*440,000*	*60,000*
Tintinnidium fluviatile Stein		*750,000*			*14,000*	*11,500*	*220,000*
Phacus longicaudus (Ehr.)		500		580		400	
Ceratium hirundinella O.F.M.		1,000					2,500
Euglena oxyuris Schmarda		*50,000*		1,100		800	
Trachelomonas volvocina Ehr.		*50,000*	*28,850*	*27,000*	*28,000*	*20,000*	*84,000*
Euglena viridis Ehr.		*100,000*	*28,000*	*55,000*	*16,000*	*22,200*	*110,000*
Dinobryon sertularia Ehr.		15,000	15,000	11,600			250
Centropyxis aculeata Stein			2,000	2,200	1,000	1,600	
Arcella vulgaris Ehr.			*25,000*	*28,000*	550	800	
Trachelomonas hispida (Perty)				*25,000*			
Pleodorina illinoisensis Kofoid					510		250
Eudorina elegans Ehr.						2,400	500
Euglena acus Ehr.							120
Pandorina morum Bory							*110,000*
ROTATORIA							
Filinia longiseta (Ehr.)	240	10,000					
Brachionus angularis Gosse	200	10,000	500	580	500	700	2,500
Brachionus capsuliflorus Pallas		3,000					
Brachionus calyciflorus Pallas		1,500					
Brachionus budapestinensis Daday		15,000				400	
Synchaeta pectinata Ehr.		500				1,200	
Brachionus patulus O.F.M.		500					
Asplanchna sp.		15,000					500
Polyarthra trigla Ehr.		90,000	15,000	8,700	1,100	12,000	1,000

TABLE II—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JUNE 25-27, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Petersburg	Chandler-ville
Keratella cochlearis (Gosse)		50,000	2,500	1,200	1,080	8,000	3,700
Lecane spinifera (Western)		1,000					
Rotaria neptunia (Ehr.)		250					250
Pedalis mira (Hudson)			1,000				
CLADOCERA							
Moina affinis Birge		30,000	500				
Diaphanosoma brachyurum (Liéven)		2,500	15,000	2,000			
Daphnia longispina (O.F.M.)		15,000	1,000	1,100			
Bosmina longirostris (O.F.M.)		10,000	1,000	5,800			2,500
Scapholeberis mucronata (O.F.M.)		500					
Chydorus sphaericus (O.F.M.)		500					
COPEPODA							
Cyclops bicuspidatus Claus		75,000	25,000	47,200	540		1,000
Cyclops viridis Jurine	240						
Immature copepods		150,000	190,000	92,000	2,700	12,000	5,000
ALGAE							
Undetermined diatoms	*1,736,460*	*2,500,000*	*2,880,000*	*1,728,000*	*1,300,000*	*1,200,000*	*1,110,000*
Gyrosigma spp.	*43,411*	*50,000*	*25,000*				
Lysigonium granulatum (Ehr.)		*25,000,000*	*8,665,800*	*2,800,000*	*1,450,000*	*1,334,000*	*2,220,000*
Closterium acutum (Lyngb.)		*50,000*					
Coelastrum microporum (Nägel)		*40,000*					*22,000*
Ankistrodesmus falcatus (Corda)		*60,000*	*288,860*	*884,000*	*56,000*		
Actinastrum hantzschi Lager		*35,000*					*21,200*
Scenedesmus quadricauda (Turp.)			*28,000*	*58,000*		*22,000*	
Pediastrum duplex Meyen			1,000	5,800	5,400	2,000	
Scenedesmus dimorphus (Turp.)				*26,000*	*28,000*	800	
Synedra tenuissima Kützt						2,400	

TABLE III.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monti-cello	Lake Decatur	Harris-town	Illiopolis	Riverton	Spring-field	Peters-burg	Chandler-ville
PROTOZOA								
Difflugia acuminata Ehr.	*15,000*					800		
Pandorina morum Bory		*400,000*			*187,200*	*24,000*	*25,500*	*69,600*
Platydorina caudata Kofoid		75,000			220			
Pleodorina illinoisensis Kofoid		125,000	660		880			
Codonella cratera (Leidy)		*1,600,000*	*490,000*	*966,000*	*1,248,000*	*1,470,000*	*357,000*	*70,000*
Difflugia lobostoma Leidy		*650,000*	*98,000*	*644,000*	*624,000*	*26,000*	*51,000*	1,260
Trachelomonas ensifera Daday		*220,000*		*32,200*	*62,000*	*73,500*	*12,000*	*70,000*
Trachelomonas hispida (Perty)		7,500			*30,000*			
Phacus longicaudus (Ehr.)		250					220	420
Euglena viridis Ehr.		*210,000*	*95,000*		*125,000*	*98,000*	*76,500*	*139,200*
Euglena acutissima Lemm.		750						*46,500*
Ceratium hirundinella O.F.M.		8,700	650	7,100	1,320			2,520
Phacus pleuronectes (O.F.M.)		250						
Tintinnidium fluviatile Stein		*120,000*	*25,500*	*30,000*	*60,000*	*122,500*	*51,000*	*140,000*
Eudorina elegans Ehr.		*410,000*		*32,000*	*31,000*	*12,000*		*70,000*
Euglena oxyuris Schmarda		*21,000*		*32,000*	*30,000*			*11,000*
Dinobryon sertularia Ehr.		12,500	19,800	5,400				
Trachelomonas volvocina Ehr.		*30,000*	*49,000*		*62,000*	*245,000*	*76,500*	
Centropyxis aculeata Stein			600	2,160	850	400	440	
Arcella vulgaris Ehr.				4,320				
Gonium pectorale O.F.M.					220			

TABLE III—Continued.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monti-cello	Lake Decatur	Harris-town	Illiopolis	Riverton	Spring-field	Peters-burg	Chandler-ville
ROTATORIA								
Brachionus calyciflorus Pallas	260	112,500	28,400	48,600	400			
Brachionus capsuliflorus Pallas		5,000	650	540	1,200	400	220	
Brachionus budapestinensis Daday		187,500	6,600	32,400	890	400		
Brachionus angularis Gosse		10,000	13,200	21,600		1,600	440	
Trichocerca pusilla (Jennings)		5,000	660	550				
Filinia longiseta (Ehr.)		62,500	9,900	37,800	13,200	6,000		1,260
Trichocerca gracilis (Gosse)		12,500		5,400	1,300	800	400	
Asplanchna sp.		70,000	1,980	16,200	880	400		
Polyarthra trigla Ehr		75,000	33,000	64,800	4,400	450	1,320	1,300
Keratella cochlearis (Gosse)		2,500	13,200	81,000	35,200	8,000	8,800	12,600
Synchaeta pectinata (Ehr.)		225,000	2,640	2,700	2,200	2,000	450	
Pedalia mira (Hudson)		87,500	27,000	43,200	1,760			
Brachionus patulus O.F.M.		250		270				420
Diurella stylata Eyferth		250						
Conochiloides natans (Seligo)		250		1,620				
Schizocerca diversicornis Daday								
CLADOCERA								
Diaphanosoma brachyurum (Liéven)	250	9,900	2,700					
Moina affinis Birge	500	650	540					
Daphnia longispina (O.F.M.)		660	540					
Bosmina longirostris (O.F.M.)		650						

TABLE III—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
COPEPODA								
Cyclops bicuspidatus Claus............		5,500	5,200	5,400	880	800	880	3,800
Diaptomus siciloides Lillje............		120	650	550	440			
Immature copepods	260	37,500	19,800	5,500	2,200	800	880	25,200
ALGAE								
Undetermined Diatoms	*936,000*	*5,000*	*735,000*	*322,000*	*1,560,000*	*490,000*	*25,000*	*3,480,000*
Gyrosigma sp.	*15,500*		*980,000*	1,620	450	*24,500*		
Closterium acutum (Lyngb.)..........	250							
Lysigonium granulatum (Ehr.)........		*10,000,000*	*4,900,000*	*644,000*	*1,872,000*	*49,000*	*127,500*	*139,200*
Scenedesmus quadricauda (Turp.).....		*40,000*			*31,200*	*24,000*		
Scenedesmus dimorphus (Turp.)......		*20,000*	*25,500*			*23,000*	*25,500*	
Pediastrum duplex Meyen............		2,500			870	1,600	440	2,520
Synedra tenuissima Kütz.............		12,500	*980,000*	2,160	880	2,400	880	
Pediastrum simplex Meyen............		240						
Actinastrum hantzschi Lager..........		*20,000*	*24,000*	*32,000*	*30,000*	*24,500*	*26,000*	*70,000*
Coelastrum microporum Nägel.........		230						
Surirella robusta Ehr.................			650					
Sphinctocystis librilis (Ehr.)..........					*31,000*			
Closterium moniliferum (Bory).......								1,260
Aphanocapsa sp.								1,300

TABLE IV.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
PROTOZOA								
Difflugia acuminata Ehr.	250		*27,000*	1620	920	500		
Eudorina elegans Ehr.	250	220					480	5,600
Ceratium hirundinella O.F.M.	250	880						
Euglena viridis Ehr.	*62,000*	*1,222,100*	*1,310,000*	*1,400,000*	*97,600*	*1,385,000*	*400,000*	*534,000*
Pleodorina illinoisensis Kofoid		200				500		
Euglena oxyuris Schmarda		*60,000*	*30,000*	*35,000*	*24,000*		*160,000*	
Difflugia lobostoma Leidy		*288,000*	*32,000*	*12,000*	*25,000*	*28,000*	*20,000*	
Codonella cratera (Leidy)		*489,000*	*27,000*	*14,000*	*10,000*	*27,000*	*40,000*	2,800
Phacus longicaudus (Ehr.)		*24,400*	*14,000*	540	1,380	500	1,920	
Trachelomonas hispida (Perty)		440	*27,700*			*2,770,000*	*1,600,000*	
Chlamydomonas spp.		*488,840*				*6,925,000*		
Arcella vulgaris Ehr.			*28,000*	5,500	3,060	5,000		280
Centropyxis aculeata Stein			480	1,080				
Trachelomonas volvocina Ehr.			*1,668,000*	*1,750,000*	*1,220,000*	*48,475,000*	*6,400,000*	*2,670,000*
Phacus acuminata Stokes			*13,000*				*34,000*	
Trachelomonas ensifera Daday				*70,000*	*25,000*	*1,385,000*	*4,000,000*	
Phacus pleuronectes (O.F.M.)				250		500		
Euglena acutissima Lemm.				*70,000*	*20,000*		*80,000*	
Glenodinium sp.					*45,000*	*28,000*	*75,000*	
Tintinnidium fluviatile Stein					*976,000*	*21,930,000*	*4,000,000*	*26,700*
Pandorina morum Bory					*24,400*		480	
Gonium pectorale O.F.M.						*14,000*		
Platydorina caudata Kofoid							2,880	

TABLE IV—Continued.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monti-cello	Lake Decatur	Harris-town	Illiopolis	Riverton	Spring-field	Peters-burg	Chandler-ville
ROTATORIA								
Brachionus angularis Gosse...........	250	2,640	240				960	1,400
Brachionus budapestinensis Daday.....	250							560
Brachionus calyciflorus Pallas.........	250	850			1,840	375,000	196,800	67,200
Distylla spinifera Western.............	250				1,600			
Polyarthra trigla Ehr..................	250	8,800	480		500	15,000	1,920	1,400
Synchaeta pectinata (Ehr.)............	250				980		9,600	
Asplanchna sp.	120						950	
Keratella cochlearis (Gosse)...........		860	480		230			
Brachionus capsuliflorus Pallas........				250	9,200	80,000	2,400	2,800
Synchaeta stylata Wierz...............					13,800	1,050,000	384,000	8,400
Trichotria tetractis (Ehr.)............					5,060			
Diurella stylata Eyferth..............						500		
Trichocerca pusilla (Jennings)........						5,000		
Trichocerca gracilis (Gosse)..........						10,000		
Asplanchna sp.						1,000		2,100
Rotaria neptunia (Ehr.)..............							480	
Trichocerca stylata (Gosse)...........							450	
Annureopsis fissa (Gosse)............								270
CLADOCERA								
Diaphanosoma brachyurum (Liéven)...		450						
Daphnia longispina (O.F.M.)..........		4,500						

TABLE IV—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
COPEPODA								
Diaptomus siciloides Lillje		6,600	4,800	600	250			
Cyclops viridis Jurine	110	450						
Immature copepods		52,800	9,600	1,200	50	500	900	2,900
ALGAE								
Undetermined diatoms	*3,120,000*	*1,222,100*	*55,550,000*	*35,000,000*	*3,660,000*	*11,080,000*	*10,000,000*	*53,400,000*
Gyrosigma spp.	*936,000*		*277,750*	*350,000*	*732,000*	*28,000*	*160,000*	*1,602,000*
Sphinctocystis librilis (Ehr.)	*15,000*		960					550
Schroederia setigera (Schröder)	*31,200*							
Cyclotella spp.		*2,444,200*				*27,700,000*		*26,700,000*
Pediastrum duplex Meyen		440	7,200	16,200	9,200	45,000	192,000	56,000
Lysigonium granulatum (Ehr.)		*3,660,300*	*22,220,000*	*17,500,000*	*244,000*	*11,080,000*	*4,000,000*	*1,335,000*
Scenedesmus quadricauda (Turp.)		2,200	*111,100*	*1,050,000*	*122,000*	*1,662,000*	*9,600,000*	*2,136,000*
Closterium acutum (Lyngb.)		*122,000*	*277,750*	*350,000*	*24,000*	*13,000*	*800,000*	*276,000*
Selenastrum gracile Reinsch		220						
Closterium acerosum (Schrank)			960				480	
Closterium moniliferum (Bory)			480					540
Ankistrodesmus falcatus (Corda)			*84,713,750*	*14,000,000*	*45,000*	*554,000*	*800,000*	*1,602,000*
Scenedesmus dimorphus (Turp.)			*55,550*	*35,000*	*46,000*	*210,000*	*800,000*	*560,000*
Synedra tenuissima Kütz			*416,625*	*700,000*	*125,000*	*1,108,000*	*70,000*	*534,000*
Coelastrum microporum Nägel				*10,000*	*12,000*	*25,000*	*75,000*	*26,000*
Cosmarium sp.				*10,800*	1,820			
Actinastrum hantzschi Lager				*700,000*	*24,000*	*12,465,000*	*3,200,000*	*1,835,000*
Micratinium pusillum							1,440	5600
Surirella robusta Ehr.					4,600			
Pediastrum simplex Meyen							450	

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AQUATIC LIFE IN WATERS POLLUTED BY ACID MINE WASTE*

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A visitor to coal mining regions for the first time usually remarks the colored water of the streams or strip pits there. Clear red or copper colored, they are much more attractive, from an aesthetic viewpoint, than the black or milky waters produced by industrial or domestic pollution in densely populated areas.

Such copper colored waters, however, represent an extreme of industrial pollution. Coal seams contain sulfur, which, when exposed to air, oxidizes in the presence of water, and so the streams or strip pits have a very high sulfuric acid content; pH values as low as 1.8, representing 35,000 p.p.m. of acid, have been noted. Such acidities are very damaging; water works superintendents or industrial engineers needing boiler water find mine water almost useless; cattle will not drink it, and fish and most plants are quickly killed by it.

These mine runs and pits also represent an environmental extreme. Extreme environments, however, often have their inhabitants, and such is the case with the acid mine waters. One of the higher plants, the cattail, Typha latifolia, grows well in the most acid waters; and several insects, such as Chironomous, the bloodworm, caddis flies, mosquitoes, and a few beetles thrive therein. The most abundant population, however, consists of protozoa and algae, unless the bacteria, insufficiently investigated, might be more abundant.

In the past year more than 200 mine runs or pits have been personally visited and samples taken therefrom to determine their microscopic flora and fauna. The general features were noted of each location visited, the pH was determined, and, if the water was acid, a sampling station was selected which showed some pooling, if in a stream, and with an accumulation of debris in which small organisms might find lodgment. Early samples showed that suspended forms were extremely rare, and an effort was thereafter made to get those forms which might crawl or burrow into debris and bottom films. Samples taken from such situations also tended to include swimming forms, because they had been taken in still water. In April and October 1938, West Virginia mine streams and Indiana strip pits were sampled. In general, the temperatures of mine streams tend to approximate 21° C. on issuing from the mines, for mine temperatures are fairly uniform throughout the year. Strip pits, of course, tend to conform to atmospheric temperatures. Frequently, two samples were taken -- one as close to the mine mouth as possible, yet at a sufficient distance to have been seeded by surface run-off, and another from the same stream or the stream system several miles below. These two samples thus afforded opportunity to show whether animals and plants gradually invaded the stream or strip pits as acidity decreased, and also tended to show how extensive a seeding was necessary to establish life in such waters. The pH of nearby pools, streams, and swamps, not polluted by mine wastes, was determined and their flora and fauna were listed for comparison. By examining widely separated points, it was ascertained that the paucity of living species was not a local condition, but was general for acid mine waters.

Field examination of mine streams in the Spring (1) indicated abundant growths of some algae. Most usual was a green coating along banks, on debris, on rocks in the swiftest currents, and even on vertical moist rock faces. A thin brown coating was also evident at times. A heavy white growth which was common usually proved to be bacterial zooglea. Fungi were scarce, rarely forming extensive growths.

Nonbacterial microscopic organisms were composed principally of protozoa, algae, and rotifers. Table 1 shows the distribution in the plant and animal kingdoms of species found in the samples within the pH range 1.8 to 3.9. All of the commonly occurring ones were identified, but perhaps an additional 10 percent of rarely occurring species could not be recognized. Some identifications may be questionable, especially of very small forms such as the smaller chlamydomonads, which might be zoospores of Stichococcus or Ulothrix. Species definitions had to be based on rather hurried determination of morphological characters, but were usually satisfactory.

A total of 99 species of plants and animals was found living at or below pH 3.9, 85 or which were microscopic types, 76 being algae or protozoa; but the list of commonly occurring microscopic forms included only 17 species. Figure 1 shows the percentage of occurrence in all samples in which these 17 species were found. An organism was arbitrarily termed "common" if it appeared in 15 percent of the samples, "tolerant" if it appeared in 5 percent of the samples, and "adventitious" if it appeared in less than that number. This

* Presented at meeting of the Limnological Society of America, Richmond, Va., December 27-31, 1938.

TABLE 1.—*Distribution of recognized genera and species of plants and animals occurring at or below pH 3.9*

Plants	Number of species	Animals	Number of species
Thallophyta:		Protozoa:	
Fungi	2	Mastigophora:	
Algae:		Euglenidae	7
Myxophyceae	3	Protomastigina	7
Chrysophyceae:		Sarcodina:	
Chrysomonadales	3	Rhizopoda	15
Chrysotrichales	1	Heliozoa	2
Bacillarieae:		Infusoria:	
Pennales	5	Ciliata	19
Chlorophyceae:		Trochelminthes:	
Volvocales	1	Rotatoria	6
Ulotrichales	2	Gastrotricha	1
Chlorococcales	1	Nemathelminthes:	
Zynematales	6	Nematoda	1
Dinophyceae	2	Arthropoda:	
Bryophyta	1	Crustacea:	
Pteridophyta	1	Isopoda	1
Spermatophyta	1	Copepoda	1
		Arachnida:	
		Tardigrada	1
		Insecta	8
		Amphibia	1

Table 1 - Distribution of recognized genera and species of plants and animals occurring at or below pH 3.9.

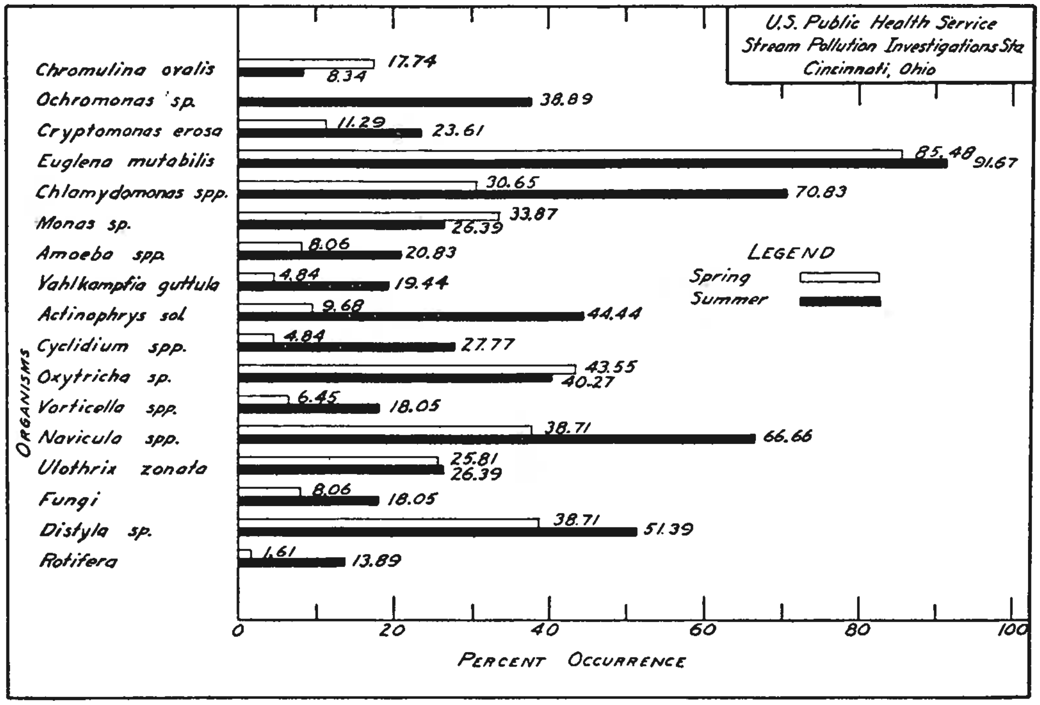


Figure 1 - Percentage of occurrence of the 17 most common organisms in all samples.

arbitrary classification is, of course, open to criticisim, but it serves as a working basis. One of its worst features is that occasionally an organism might be found in but a single sample, yet occur in such large numbers in that sample as to leave no doubt of its tolerance for that particular environmental niche. As an example of this might be mentioned the large numbers of Lepocinclis ovum which were present in Crab Orchard Creek (pH 2.5), where it was the dominant one of six species of microorganisms; or the large number of Raphidiophrys pallida in Riverdale (pH 3.0). Both of these would normally be listed as adventitious forms, but in the particular samples under consideration they were decidedly not. Amoeba radiosa is also listed as an adventitious form, but in laboratory cultures of this mine water it may attain large numbers.

Because of the seasonal differences between the first and last sampling periods (early spring and late summer, respectively), considerable differences in the flora and fauna were anticipated. Actually, very little difference was found. Ochromonas sp., common in later summer, was not found in spring, and the same is true for the small amoeba, Vahlkampfia guttula. Chromulina ovalis, common in spring, was found in 11 of the early samples and in only 6 of the later ones. Frequently, however, it was found impossible to distinguish between this creature and Ochromonas, and it seems probable that some of those listed as Chromulina in the spring samples were Ochromonas. The 17 varieties of common forms appeared in more samples in the late summer, except for Pleuromonas jaculans and Urotricha farcta. Even for the adventitious species the two sets of samples showed largely the same forms, the greatest difference being among the ciliates and rhizopods.

Nor can the species which were encountered be termed rare. Euglena mutabilis (Fig. 2) is far from common unless in an acid situation, but has been recorded by the writer (2) 11 times in 165 samples over a period of several years, while Prof. W. J. Kostir (3), of Ohio State University, has maintained a pure culture of it over a long period. Neither the Chromulina (Figs. 3, 4) nor the Ochromonas (Fig. 5) fit exactly into those species given by Pascher and Lemmermann (4), but they hardly exhibit sufficient differences to be called new species. Three of the ciliates, Chilodonella, Cinetochilum, and Glaucoma, have been shown elsewhere (2) to tolerate wide differences of environment. Probably it is just such species, i.e., those with a wide tolerance, which we might expect to find in these acid waters. The condition has been created largely by man and is, therefore, relatively recent; such

AQUATIC LIFE IN ACID WATERS

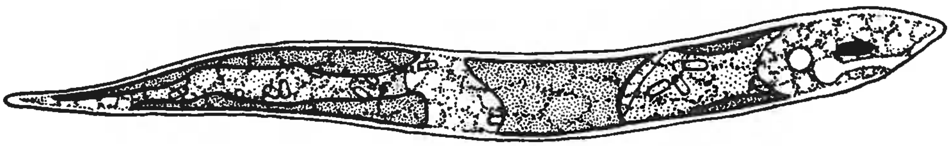
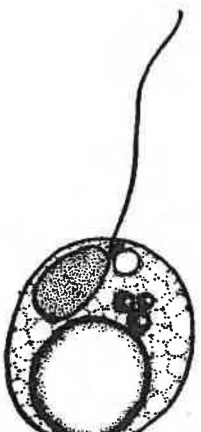
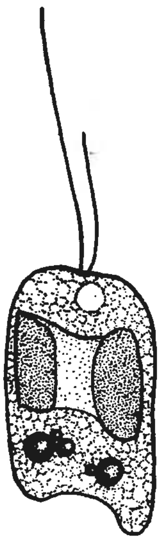
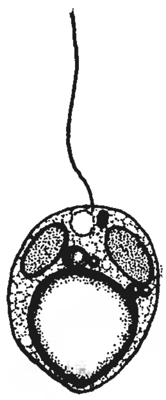


Figure 2 - Euglena mutabilis, showing two or three heavy chloroplastids, conspicuous stigma, small rod-like paramylum bodies, and apparent absence of flagellum.
like paramylum bodies, and apparent absence of flagellum.







Figures 3 and 4 - Chromulina sp., showing one or two chromatophores, stigma, and large posterior granula.
Figure 5 - Ochromonas sp., showing band-like chromatophore and absence of stigma.

species as could occupy the environment have done so, but few, if any, new ones have developed. The absence of acid-tolerant forms is marked for the desmids and shelled rhizopods of bog habitats; but we are dealing here with higher acidities than those of bogs and with a mineral acidity rather than organic acidity.

There is a very large difference between the total number of species found in one of these highly acid samples and in a sample from a stream of stagnant pool or strip pit immediately adjacent to the mine water sample, but whose pH is near neutrality. Any mine water sample could be repeatedly examined with great care day after day and never show more than a few species of microorganisms. Figure 6 shows the average number of species per sample at observed pH values up to and including 3.9. Between pH 3.9 and 4.8 very few samples were obtained; but at 4.8 and above, the number of species which could be counted increased greatly. Thus, 15 samples from pH 4.8 to 7.2, secured for comparison in the early spring trip to the mine fields, showed an average number of 23 microscopic species per sample, and the notation was made for each of these samples: "A complete list * * * not compiled * * *." Almost any 100-ml sample of Scioto River (Ohio) water, taken at the same time of year, will show from 60 to 120 plankton species alone. It is an inevitable conclusion that the highly acid waters greatly diminish the number of possible inhabitants therein.

A number of Indiana and Illinois strip pits have been dammed at various times, raising the water above the exposed coal seams and creating long and often deep and beautiful lakes. Here there is little or no chance for the oxidation of sulfur to sulfuric acid. The result is a very slow decrease in acidity and a subsequent slow repopulation of the lake by microorganisms, then by fish and other animals. The Tygart River at Phillipi, W. Va., gave a sample whose pH was 6.0 and which yielded 44 microscopic species on an incomplete examination. The river was clear and green at that point because of algae growing on submerged objects, yet a few years ago, before the sealing of mines in this region, it was a highly acid stream, "red and nothing would grow in it." No data were available on the succession of forms reinvading gradually improving streams or lakes, but copepod Crustacea were found in enormous numbers in two lakes, one with a pH of 6.6, and in the Tygart River. Because the strip pit lake is usually surrounded by high, steep banks and its total watershed area is hardly greater than the lake area, it must depend on photosynthetic protozoa and algae for fertility. The high, steep banks can contribute no humus for feeding the organisms initiating food chains, and either there are no shallow areas for growth of higher plants, or else the acid tolerant Typha preempts such areas and is, apparently, a poor "fertilizing" plant. The general impression is that recovery of a highly acid strip pit to a productive body of water is a slow process if left to nature.

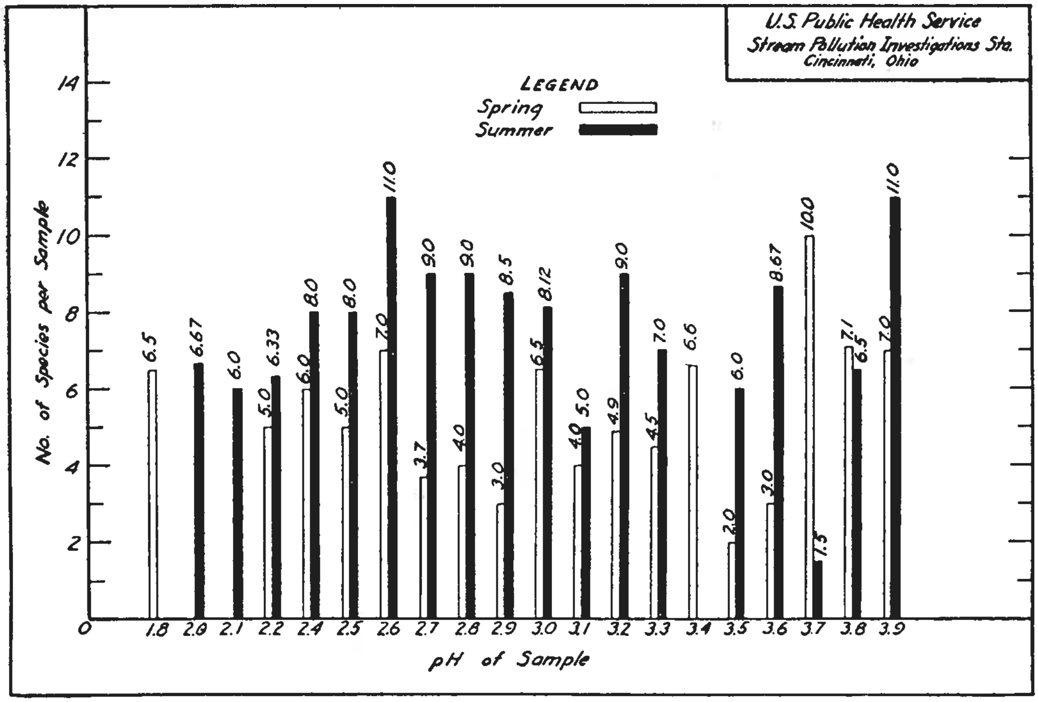


Figure 6 - Average number of species per sample within the pH range 1.8 to 3.9.

SUMMARY

Two coal mining regions, shaft mining areas in West Virginia, and strip mining areas in Indiana and Illinois, were visited and biological surveys twice made of their highly acid streams and strip pit lakes. A few adjacent almost neutral streams and lakes were surveyed for comparison.

A total of 86 species of microscopic forms was recognized. Besides Thallophyta, Protoza, and Trochelminthes, only one of the remaining phyla of plants and animals, the Arthropoda, was represented by more than one commonly occurring species in these acid waters.

At or below pH 3.9, the number of species found in any given habitat was very small. The largest number was 11 at pH 2.6 and several samples showed no life on examination.

Practically the same forms were common in April and October, but there was quite a difference in the species termed adventitious which were found at the two different times.

Seventeen species occurred in 15 percent or more of the samples and are termed "common." The most frequently occurring ones were as follows: Euglena mutabilis, Naviculoid diatoms, Chlamydomonas spp., Distyla sp., Actinophrys sol., Oxytricha sp., Ochromonas sp., and Ulothrix zonata.

Because the most sharply definitive factor, sulfuric acid acidity, remains relatively constant, the relative constancy of species occurrence indicates that this one factor outweighs all others.

After the strip pit lakes have been sealed to reduce acid production there appears to be little chance for them to become productive except by the initial development of a large flora and fauna of chlorophyll-bearing organisms. Inasmuch as seven of the 17 organisms most common in this environment belong to this category, this initial process is apparently already under way.

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75(1945) : 175-180

A HEAVY MORTALITY OF FISHES RESULTING FROM THE DECOMPOSITION OF ALGAE IN THE YAHARA RIVER, WISCONSIN

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and

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ABSTRACT

A heavy loss of fish occurred in the Yahara River below Lake Kegonsa, Wisconsin, during the latter part of September and the early part of October, 1946. All species of fish in the river were affected in the mortality. The fish, crowded close to shore, were breathing at the surface and showed marked signs of distress before expiring.

Chemical analyses of the water were made in successive periods, and experiments were performed to determine the toxicity of the river water to experimental fish. Death was attributed primarily to the depletion of the oxygen supply by the decomposing algal mass consisting of almost a pure culture of Aphanizomenon flos aquae. Secondarily, toxic substances liberated into the water by the decomposing algae probably contributed to the death of the fish.

INTRODUCTION

A heavy loss of fish occurred in that portion of the Yahara River from the Lake Kegonsa Lock downstream to its confluence with the Rock River during the latter part of September and the early part of October, 1946. Although many thousands of fish were observed, no estimate was made of the number. Carp (Cyprinus carpio) were the predominant fish affected. Other species observed were northern pike (Esox lucius), yellow pike perch or walleye (Stizostedion v. vitreum), black crappies (Pomoxis nigro-maculatus), bluegills (Lepomis macrochirus), suckers (Catostomus commersonnii), black bullheads (Ameiurus m. melas), buffalo (Ictiobus bubalus), hog suckers (Hypentelium nigricans), and an eel (Anguilla bostoniensis).

A series of eight representative stations was established in the 17 miles of river between the Lake Kegonsa Lock and the Rock River to study the progress of the mortality (Fig. 1).

PROGRESS OF THE MORTALITY

A huge algal mass estimated between three and four acres in area and several inches thick was moved into the bay above the Lake Kegonsa Lock by westerly winds and accompanying wave action on September 25, 1946. To prevent undesirable odors, the mass was permitted to pass through the lock by the lock tender over a 6-hour period. On September 28, 1946, it was reported that a heavy fish mortality was occurring at Stoughton, Wisconsin, 3-1/2 miles below the lock. Upon investigation many dead and dying fish were seen at Station 2. The fish that were still alive showed signs of acute distress and were packed close to the shore, gasping at the surface. The bay at this location provided a concentration point for fish which undoubtedly were driven out of deeper water by the oxygen deficiency caused by decomposition of the algal mass (Fig. 2). Dead fish were seen floating through the lock at Stoughton, Wisconsin, located at Station 3.

On October 1, 1946, mortality was apparent at Station 4 which is 2-1/2 miles below the previous station. Over 8,000 carp, averaging 4 pounds each, were crowded into a shallow, spring-fed stream about 500 feet long and 4 feet wide which empties into the Yahara River near this station. Above a natural fish barrier in the stream the water contained 9.6 p.p.m. of dissolved oxygen but in the lower portion there was no oxygen. The carp lived in the section of the stream where the oxygen supply remained adequate for their needs (Fig. 3).

On October 3, 1946, the mortality had reached Stations 5 and 6, located 8 miles down the river. The conditions found here were similar to those at the previous stations.

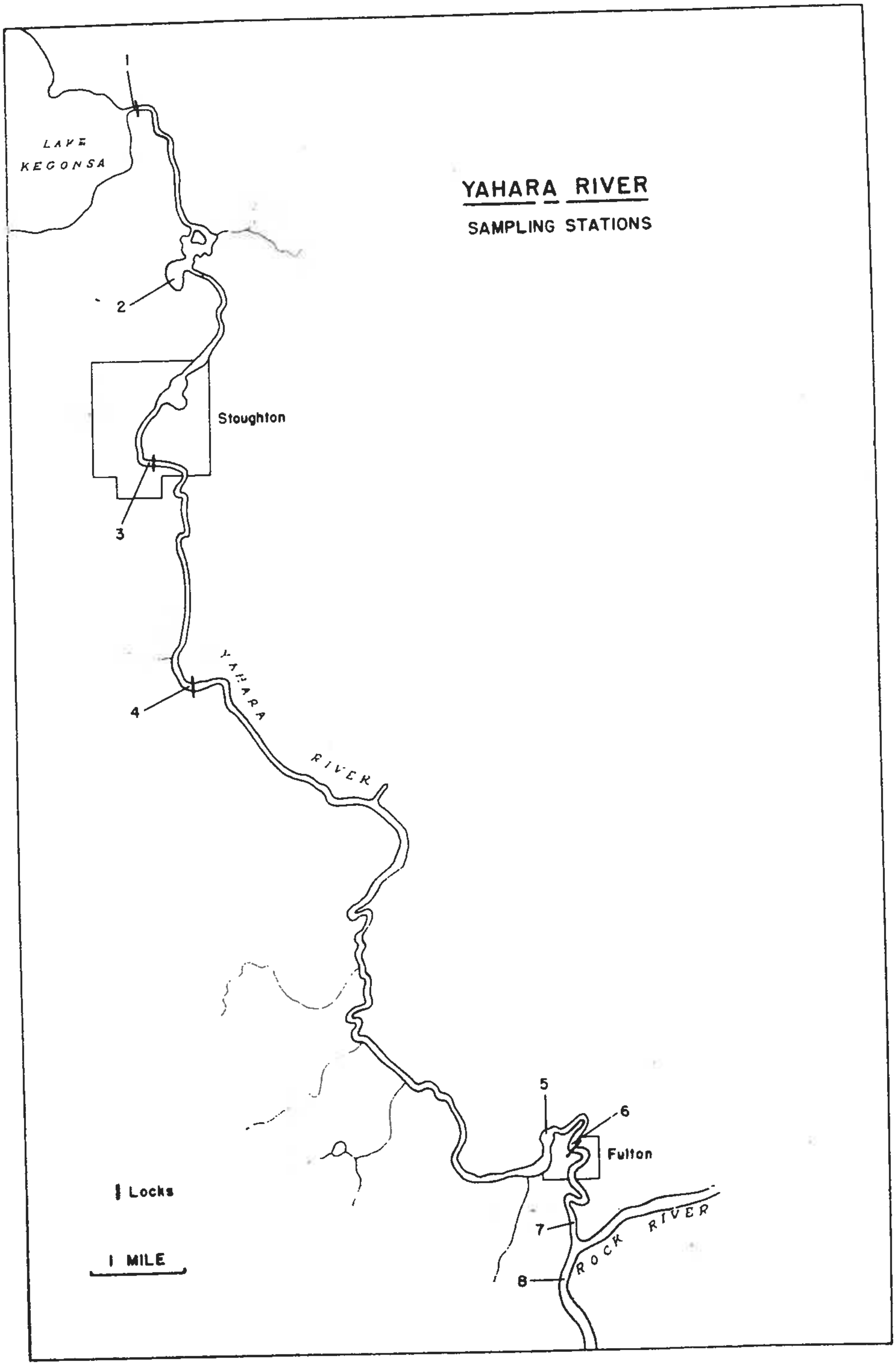

Figure 1 - Station locations on Yahara River, Wisconsin.

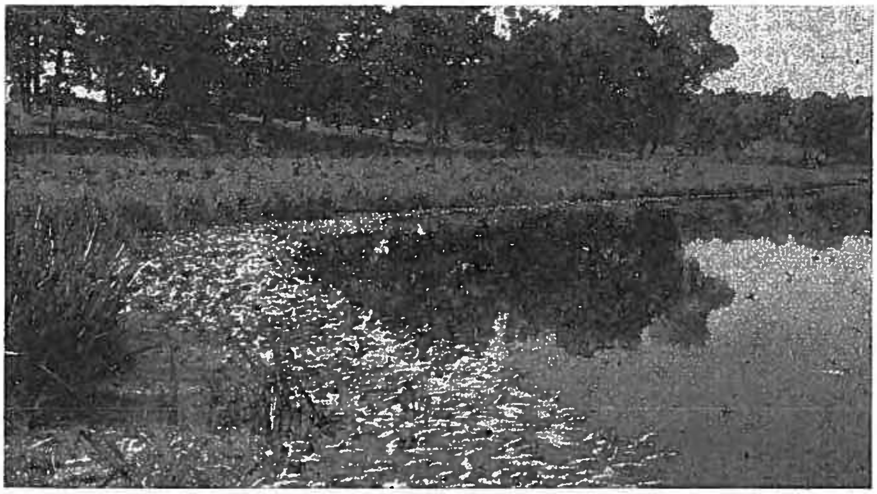

Figure 2 - Dead fish in bay of Yahara River.

Item	Date	Stations							
		1	2	3	4	5	6	7	8
Air temperature (F.°)	Sept. 28	....	58	58	....	....	....	....	....
	Oct. 1	66	66	66	....	....	....	....	....
	do. 3	....	72	72	72	72	72	72	72
	do. 5	....	68	68	68	68	....	....	....
	do. 9	....	66	66	66	66	66	....	....
Water temperature (F.°)	Sept. 28	....	62	62	....	....	....	....	....
	Oct. 1	64	64	56	....	....	....	....	....
	do. 3	....	64	58	59	60	60	60	60
	do. 5	....	62	63	61	64	....	....	....
	do. 9	....	62	60	61	61	61	....	....
Dissolved oxygen (p.p.m.)	Sept. 28	....	0.0	0.3	....	....	....	....	....
	Oct. 1	10.2	0.4	0.8	0.8	....	....	....	....
	do. 3	....	1.5	1.8	2.4	0.2	0.1	1.0	7.8
	do. 5	....	1.8	3.7	3.8	4.5	4.3	....	....
	do. 9	....	5.1	6.4	7.8	10.0	10.4	....	....
Free carbon dioxide (p.p.m.)	Sept. 28	....	43.0	30.0	....	....	....	....	....
	Oct. 1	0.0	17.5	7.0	7.0	....	....	....	....
	do. 3	....	14.0	5.7	5.5	11.5	14.4	8.0	0.0
	do. 5	....	3.5	2.0	3.0	2.0	4.0	....	....
	do. 9	....	1.0	0.0	0.0	0.0	0.0	....	....
Hydrogen-ion concentration (pH)	Sept. 28	....	7.0	7.0	....	....	....	....	....
	Oct. 1	....	7.2	7.3	....	....	....	....	....
	do. 3	....	7.3	7.7	7.4	7.4	7.3	7.4	....
	do. 5	....	7.6	7.6	7.6	7.6	7.6	....	....
	do. 9	....	7.7	8.0	8.0	8.4	8.4	....	....
Days of maximum fish mortality	Sept. 28	....	xxxx	xxxx	....	....	....	....	....
	Oct. 1	....	....	....	xxx	....	....	....	....
	do. 3	....	....	....	....	xxxx	xxxx	....	....

Table 1 - Temperature and chemical characteristics of Yahara River during the period between September 28 and October 9, 1946.

Figure 3 - Carp crowding into small spring-fed stream.

WATER CONDITIONS

An examination of the river water at the time of the fish mortality showed a concentration of the blue-green alga, Aphanizomenon flos aquae.

The results of temperature and chemical determination are shown in Table 1. At the time of greatest mortality, the oxygen content was less than 1 p.p.m., the free carbon dioxide was high, and the pH was low. It is believed that the depletion of oxygen in the river forced the fish into the shallow bays. The greatest fish mortality seemed to take place when the decaying algal mass moved downstream. Twelve days elapsed before the water returned to a condition suitable for fish life at Stations 2 and 3. The lower stations returned to normal more rapidly because there was greater dilution of the algal mass and more wave action.

EXPERIMENTS ON TOXICITY OF RIVER WATER

An attempt was made to determine experimentally the toxicity of substances in the river water. A sample of water was taken from Station 2 during the period of greatest mortality, placed in an aquarium, and aerated. A control was set up using aerated spring water. Two yellow perch (Perca flavescens) and two black crappies (Pomoxis nigro-maculatus) were placed both in the experimental and the control aquaria. After a period of 30 hours all experimental fish had died but the control fish were still living. The oxygen in the experimental tank at the end of the same period was 8.3 p.p.m.

On October 3, 1946, a similar experiment was conducted with water taken at Station 6, 14 miles down the river. Seven yellow perch, four black crappies and one common sucker (Catostomus commersonnii) were placed both in the experimental and the control aquaria. The yellow perch began to lose their equilibrium on October 6, 1946, and began to die on October 8, 1946. All of the fish in the experimental tank were dead on October 11, 1946, but the control fish remained alive. It is believed that the fish lived longer in this than in the earlier experiment because the algal mass was dispersed and the toxic substances diluted to such an extent that they were less harmful at the lower stations along the river.

CONCLUSIONS

It is concluded from the temperature and chemical data and from the results of experiments that the primary cause of the fish mortality was the depletion of the oxygen supply brought about by decomposition of a huge mass of Aphanizomenon flos aquae. Secondarily, toxic elements released by the decomposing algae probably increased the mortality.

An examination of the literature indicates that mortality produced by the decomposition of certain blue-green algae is not a new phenomenon. Fitch et al. (1934) who reviewed the literature on the effects of algal poisoning upon domestic animals pointed out that cattle, sheep, hogs, chickens, ducks, turkeys, and geese have been known to die soon after drinking water that contained a heavy algal growth. Rabbits and guinea pigs died suddenly after being inoculated intraperitoneally with algal suspensions extracted from live algae. Prescott (1939) stated that heavy growths of phytoplankton will deplete the oxygen supply during warm still nights and that the exhaustion of the oxygen brings about the death of both microfauna and phytoplankton. The decomposition by bacteria of this mass of organic matter quickly reduces further the oxygen content. As a result, the fish and other aquatic animals are suffocated. Prescott stated further that, "it is apparently possible for algae to bring about the death of fish through the liberation of substances toxic to them during the decay process. When highly proteinaceous blue-green algae undergo decay, sufficient quantities of hydroxylamine and other derivatives are produced to poison any fish caught in the shallow water of a bay by masses of decaying algae."

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SUGGESTED CLASSIFICATION OF ALGAE AND PROTOZOA IN SANITARY SCIENCE

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Many types of microorganisms are of real importance in the field of sanitary science. Bacteria, molds, yeasts, protozoa and algae all play significant roles in relation to water and sewage. A limited number of them are pathogenic but the great majority are those that cause nuisance conditions in water supplies or are associated with sewage treatment and stream self-purification.

CLASSIFICATION OF PIGMENTED FLAGELLATES

Confusion exists in the literature of sanitary science in the classification of a considerable number of microorganisms. The confusion is especially evident in dealing with certain organisms which are on the borderline separating algae of the plant kingdom from protozoa of the animal kingdom, where one investigator may classify a particular organism with the algae and another place the same organism with the protozoa (1) (2).

The organisms most often involved in this confusion are those known as pigmented flagellates which have both the protozoan characteristic of being able to swim by means of flagella, and the algal characteristic of photosynthesis made possible by the presence of the pigment chlorophyll. Thus, they are intermediate between typical algae and typical protozoa, and it would depend upon which characteristic was emphasized as to whether they would be listed in the plant kingdom as swimming, flagellate algae, or in the animal kingdom as photosynthetic pigmented* protozoa. It is the authorities in the fields of protozoology and algology who are responsible for the existing confusion, since they have come to no agreement as to the classification of the organisms involved.

In an attempt to resolve opinions among authorities concerned with the characteristics an organism should have in order to be classified as a protozoan or as an alga, a large group name, the Protista, was proposed by Haeckel (3). Under it all protozoa and all one-celled algae were lumped together without distinction. The term "Protista" has not received general recognition and would be of little or no value to the sanitary scientist.

EXISTING CONFUSION IN SANITARY SCIENCE

A recent book, "Water Quality Criteria" (4) serves to illustrate the existing confusion in classification of microorganisms. The pigmented flagellate, Synura is listed on page 170 as an alga, and later, on page 333, as a protozoan. Lackey (5) in his paper, "Protozoan Plankton as Indicators of Pollution in a Flowing Stream," referred many organisms to the protozoa that he, in other papers, classified as algae, (1) (6). Turre (7), who has published photomicrographs of algae in water supplies, includes Volvox with the green algae, while Dinobryon and Synura are listed under protozoa. He considers the protozoa as one group of algae.

Mohr (8), in his paper on protozoa as indicators of pollution, lists the chlorophyll-bearing Euglena with the organisms Paramecium and Vorticella, which are nonpigmented protozoa. Brinley (9) lists the pigment-containing Ceratium and Peridinium as protozoa. Thomas and Grainger (2), in their book, "Bacteria," refer the pigmented flagellates Chalmydomonas, Uroglena, Synura, and Dinobryon, to a class of protozoa, the Mastigophora. Cox (10), in his book, "Laboratory Control of Water Purification," lists the following as protozoa: Dinobryon, Euglena, Uroglena, Synura, and the unrelated nonpigmented protozoan parasite Endamoeba histolytica. Hale (11), in recommending chemicals required for control of organisms, lists ten genera, including Chlamydomonas, under protozoa with only two nonpigmented genera in the list, namely, Bursaria and Endamoeba. Other pigmented flagellates, including Pandorina and Volvox which are closely related to Chlamydomonas, are placed with the algae. Hopkins (12) lists ten genera of chlorophyll-bearing organisms under protozoa in a table reproduced from Hale (13). Whipple, Fair, and Whipple (14) list some of the pigmented flagellates as protozoa and others as algae. In "Water Quality Criteria" (4), Synura, Dinobryon, and Uroglenopsis, all containing photosynthetic pigments, are listed under protozoa in a discussion of domestic water supplies along with such true nonpigmented protozoan parasites as Endamoeba histolytica and Balantidium coli. Pigmented forms such as Gymnodinium, Gonyaulax and Peridinium

* "Pigmented" refers to chlorophyll and other photosynthetic pigments only.

are listed as protozoa in a discussion of their relation to fish and shellfish mortality. Gonyaulax catenella, a pigmented form responsible for mussel poisoning, is considered only as a protozoan.

Writers in the field of sanitary science who have placed pigmented flagellates under the algae include Kehr et al. (15), Hobbs (16), Prescott (17), Brinley and Katzin (18), Gainey and Lord (19), and Sorensen (20). Modern workers in the field of algology also follow this practice, including Fritsch (21), Smith (22), Tiffany and Britton (23), and Prescott (24).

SIGNIFICANCE OF OXYGEN-PRODUCERS

The relationship of microorganisms, including the flagellates, to oxygen is particularly significant, especially when considering their role in treatment of sewage and in stream self-purification. The amount of dissolved oxygen is one of the limiting factors in determining the speed with which microorganisms will bring about the modification of sewage in a treatment plant or of organic wastes in a stream.

It is assumed from results of research, to date, that all organisms containing chlorophyll and other related pigments are capable of carrying on the process of photosynthesis. In this process the organisms remove carbon dioxide and water from the environment and, in the presence of light, produce oxygen and carbohydrates. Much of the oxygen is released by the organism into the water, whereas the carbohydrate is retained. The photosynthetic organisms are therefore recognized as oxygen producers.

Nonphotosynthetic organisms undergo no process by which oxygen would be released into the water. These nonpigmented forms carry on the process of respiration in which the relationship of carbon dioxide and oxygen are the opposite to that in photosynthesis since available oxygen from the environment is utilized and carbon dioxide is released. The pigmented organisms also carry on respiration in addition to photosynthesis, but during the hours of daylight the latter takes place at a much higher rate. The supersaturation of natural waters with oxygen, which is frequently encountered, is usually a result of photosynthesis. In darkness, with no photosynthesis taking place, the pigmented organisms behave in a manner similar to the nonpigmented, both groups using oxygen and releasing carbon dioxide. When the sum of the effects occurring in a typical diurnal-nocturnal cycle are considered, however, the pigmented organisms are recognized as oxygen-producers and the nonpigmented ones as oxygen-consumers. If present and active in large numbers, the oxygen-producers stimulate oxidation of organic wastes by the oxygen-consuming organisms. Both oxygen-producers and oxygen-consumers, therefore, are distinct and important groups of microorganisms for the sanitary scientist to consider.

This relationship of microorganisms to oxygen is also utilized as one of the basic characteristics in their classification. Typical algae are described as oxygen-producers, and the typical molds, protozoa, yeasts, and bacteria as nonoxygen-producers or oxygen-consumers. The confusion in the classification occurs when this characteristic is not given sufficient emphasis.

A SOLUTION TO THE PROBLEM

When the oxygen and non-oxygen producers are mixed together in a classification, it is not possible to evaluate clearly their roles in water pollution problems. As has already been indicated, this type of confusion is evident in connection with the classification of the pigmented flagellates. For the sanitary scientist, it would not be difficult to overcome the confusion, because to him the oxygen-production of these organisms needs to be taken into consideration, whereas their swimming ability is of little or no importance. The sanitary scientist, therefore, should logically group the pigmented flagellates with the photosynthetic algae rather than with the nonpigmented protozoa.

In actual practice it might be difficult or impossible to recognize oxygen-production by individual organisms were it not for the fact that the visible characteristic of pigmentation is associated with that physiological phenomenon. These organisms normally possess the green chlorophyll and frequently additional pigments in amounts sufficient to be visible under a compound microscope. The pigments are located within the protoplasm of the individual cells and can be seen to be localized within the cells of the organisms in the form of one or more plastids or chromatophores. The other pigments which may be present in addition to the chlorophyll lend various shadings of color to the plastids in the cells. The shades most frequently encountered in the pigmented flagellates are green, yellow-green, and brown. Examples of some of the pigmented flagellates with their plastids or chromatophores are illustrated in Figure 1, together with some non-pigmented flagellates. It will be noted that, in either group, both unicellular and colonial types are to be found.

In addition to the sanitary scientist's need to separate organisms according to their oxygen relationship, it is desirable from another standpoint to have all organisms grouped according to one recognized classification in order to eliminate the wasteful duplication of effort. For example, if the same swimming, pigmented organism is causing an undesirable odor in a settling basin at a water treatment installation in Iowa and at another in South Dakota, it is a handicap to have the organism listed as an alga at one place and as a protozoan at the other. Because of the presence of the photosynthetic pigment, it is recommended that all workers list it as an alga. Coming to such an agreement would do away with doubt that may arise in comparing effective control measures put into practice in each area.

NONPIGMENTED FLAGELLATES

A second small group of flagellates is involved in the confusion over classification. A few nonpigmented, swimming organisms are considered by authorities to be so closely related to the pigmented swimming forms that they are often placed in the same groups with the latter rather than with other nonpigmented forms.

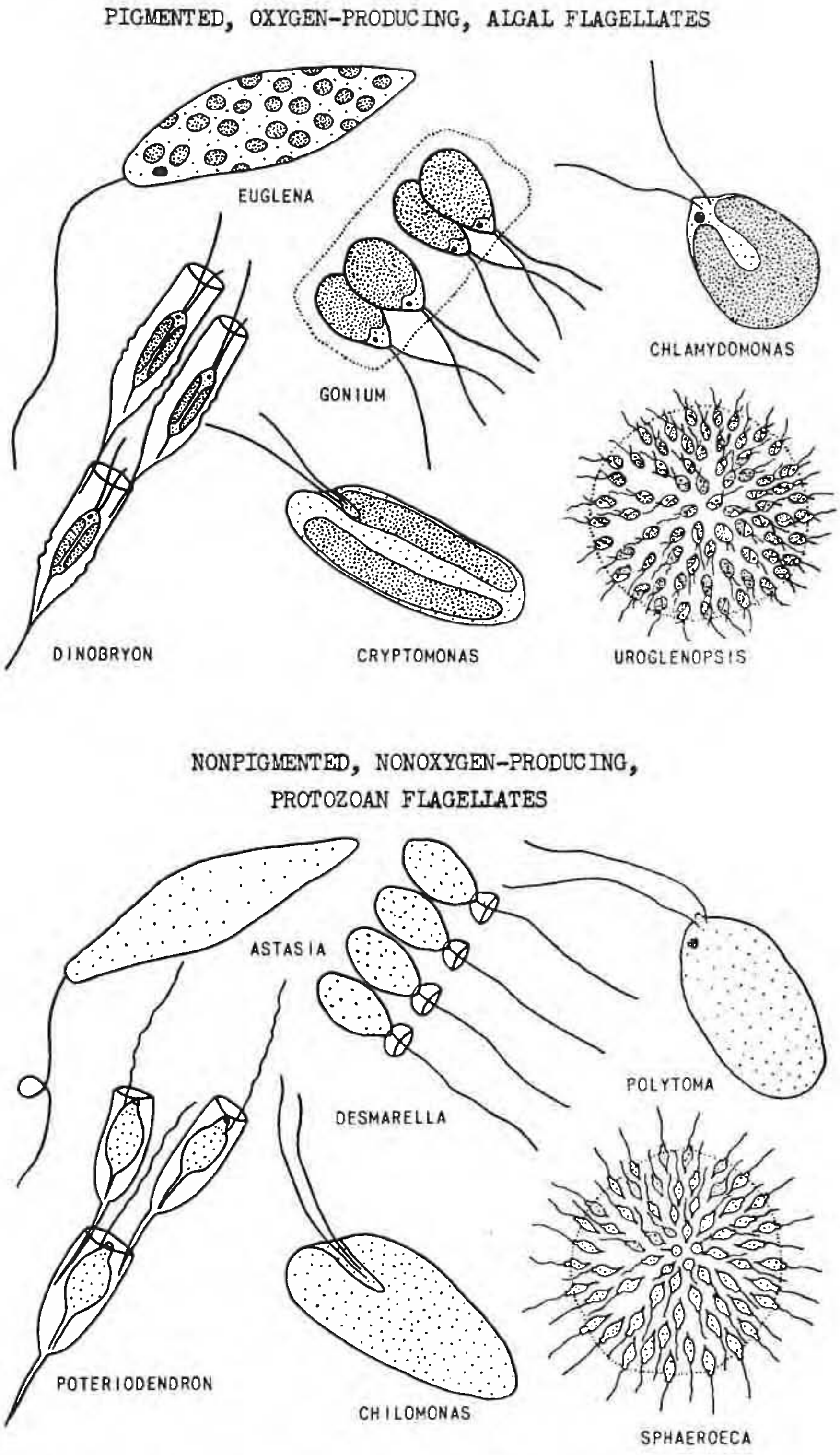

Figure 1 - Typical pigmented and nonpigmented flagellates.

Included among the nonpigmented flagellates, which have been involved in the confusion, are such genera as Astasia, Polytoma, Chilomonas, Euglenopsis, and Peranema. Thus, an algologist would consider these particular nonphotosynthetic organisms to be algae, just as many protozoologists have considered the pigmented flagellates to be protozoa.

Again, the sanitary scientist can settle this problem for himself by placing all nonpigmented (nonoxygen-producing) flagellates with the protozoa, disregarding the close evolutionary relationship between certain pigmented and nonpigmented forms.

RECOMMENDED GROUPING OF FLAGELLATE FORMS

Table I which follows, separating flagellates into two easily recognizable groups, can serve as a guide to classification for those working in sanitary science, and thus, make it possible to overcome the existing confusion. The first group includes the pigmented, photosynthetic, oxygen-producing, "algal" flagellates. The second group includes the nonpigmented, nonphotosynthetic, nonoxygen-producing, "protozoan" flagellates. In a very few cases, certain species of the genera in the first list are nonpigmented. These particular species would, of course, need to be placed in the second list.

More than 150 genera of flagellates have been reported for the United States. Some of these forms are comparatively rare and are of little or no importance to sanitary scientists. Others, however, are included among the microorganisms frequently encountered in water supplies or sewage. Organisms listed are limited to those flagellates which are considered to be of significance to the sanitary scientist.

SUMMARY

A lack of agreement exists among botanists and zoologists as to a definite line of demarcation between algae and protozoa. Consequently, there is no uniformity in the classification of a considerable number of flagellates which are important in the field of sanitary science. It is recommended, therefore, that the presence or absence of photosynthetic pigments (indicating the ability or inability to produce oxygen) be used in this field of applied science to separate the flagellates into the pigmented (algal) and nonpigmented (protozoan) types.

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TABLE I.—Classification of Flagellates

Pigmented, oxygen-producing "algal" flagellates		Nonpigmented, nonoxygen-producing "protozoan" flagellates	
Carteria	Hemidinium	Anisonema	Mastigamoeba
Ceratium	Lepocinclis	Anthophysis	Mastigella
Chlamydomonas	Mallomonas	Astasia	Menoidium
Chlorogonium	Ochromonas	Bicosoeca	Monas
Chromulina	Pandorina	Bodo	Monosiga
Chroomonas	Peridinium	Cercobodo	Noctiluca
Chrysococcus	Phacotus	Cercomonas	Notosolenus
Chrysosphaerella	Phacus	Chilomonas	Oikomonas
Colacium	Pleodorina	Clautriavia	Peranema
Cryptoglena	Pteromonas	Codonosiga	Petalomonas
Cryptomonas	Pyramimonas	Cyathomonas	Pleuromonas
Dinobryon	Pyrobotrys	Desmarella	Polytoma
Dunaliella	Rhodomonas	Dinema	Polytomella
Eudorina	Spondylomorum	Dinomonas	Poteriodendron
Euglena	Synura	Distigma	Rhabdomonas
Eutreptia	Trachelomonas	Entosiphon	Sphaeroeca
Glenodinium	Uroglena	Euglenopsis	Tetramitus
Gonium	Uroglenopsis	Heteronema	Trepomonas
Gonyaulax	Volvox	Hexamita	Tropidoscyphus
Gymnodinium	Wislouchiella	Hyalogonium	Urceolus
Haematococcus		Khawkinea	

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Chapter III

RELATIONSHIP TO POLLUTION OF BOTTOM ORGANISMS

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ECOLOGY OF ANIMAL SAPROBIA

R. Kolkwitz and M. Marsson

In the Reports of the German Botanical Society (22), we published last year the "Ecology of Plant Saprobia" which comprises about 300 species and is intended to facilitate -- as is this paper -- the evaluation of the degree of purity of streams and bodies of water.

In order to characterize the different degrees of self-purification in such waters, we distinguish three main zones and designate these by the following terms (5, 22):

I - Polysaprobiotic Zone;

II - Alpha- and Beta-mesosaprobiotic Zone;

III - Oligosaprobiotic Zone.

If we assume three adequately large and successive ponds of which the first (I) collects putrescible sewage, then the latter will have mesosaprobiotic character after passage into the second pond (II), i.e., it will be in an intermediate stage of mineralization. Upon passage into the third pond (III), the mineralization process of such water would be largely or completely terminated, i.e., the water would have an oligosaprobiotic character (15).

Zone II is asymmetrical since self-purification here takes place rather aggressively in one half of the zone and moderately in the other which explains the subdivision into alpha- and beta-mesosaprobiotic.

Similarly, we can distinguish in rivers or streams receiving putrescible substances (products of protein decomposition and carbohydrates) differing zones as far as the point at which the initial picture is re-established.

The designation of strong and/or weak mesosaprobiotic in our plant ecological system has here been replaced by alpha- and/or beta-mesosaprobiotic because the words used can give rise to misunderstandings when taken out of context by assuming strong to mean pronounced and weak as little.

As indicated by the terms themselves, the above division into zones presupposes that the action of the chemical factors predominates over that of the physical factors unless the latter control the possibility of existence entirely, e.g. turbulent flow and entrained sand along banks and/or bottom of streams.

Division into the above zones further presupposes that putrescible organic substances exercise a considerable influence on the distribution of the organisms. Proof for the accuracy of this assumption was obtained by us from numerous investigations in many waters of a great number of different regions, especially the North-German Plain. A large part of these observations has not yet been published; however, many chemo-analytical data for this and the close parallels between biological and chemical analysis of water may be found already in our communications published in the Reports of the Institute (Royal Institute for Water Supply and Sewage Disposal). These communications concern ditches and ponds of the trickle fields at Berlin, artificial lakes in the Rhineland, the lower course of the Main River, the Elbe River from Schandau to Hamburg, the Saale River from Halle to its confluence with the Elbe and the Mleczna and Gostine Rivers in Upper Silesia to the confluence with the Vistula. There are also detailed investigations of the Elbe River at and below Hamburg in its relations to the 'outflow from sewers in the extensive work of Volk.

The work of Lauterborn and Marsson indicates that the Rhine has also been examined biologically but the findings of the respective chemical and bacteriological analyses have not yet been published.

The influence of the water-soluble substances on plants is generally more direct than on the animals -- no less important for the self-purification of the waters -- because the former nourish themselves by osmosis and the latter primarily by feeding on the substances. The character of the mud may therefore be of great significance for the distribution of the animals.

The dependence on the composition of the water is especially pronounced for the lower organisms. This explains the dearth in the poly- and alpha-mesosaprobiotic zone of species of higher organisms which have in greater part a less definitely graduated distribution by zone. They are therefore represented predominantly and particularly abundantly in the beta- and oligosaprobiotic zone but may overlap from here into adjacent zones through certain representatives.

An organism reacts as much more strongly to the chemical composition of water as it is more definitely saprophil -- in addition to being saprobiotic -- from the point of view of nutritional physiology which applies e.g. to Antophysa vegetans, Carchesium Lachmanni, vorticella microstoma and others. True saprophil organisms therefore are the principal guide organisms for the chemical composition of the water. The statement (August Püteer, Nutrition of Aquatic Animals, Verworn Journal for General Physiology, Vol. 7, 1907) that appreciable amounts of water-soluble organic substances also serve the nutrition of the animals would appear from the above to be valid in sweet water essentially only for certain lower organisms.

As we have stressed frequently, the main emphasis in the evaluation of the waters should in general not be laid on the individual organisms but on the biocenoses ("Bioconosen") whose particularities cannot here be described in detail. In this respect, we may well apply here the maxim coined by the systematicians according to which one (a single) character is no character. Only in tests of drinking water is it possible for isolated organisms to play an essential role as is frequently shown in the pertinent literature.

The clearest picture of the state of the water will obviously be obtained by a planned consideration of the three typical regions of open water, bank and bottom, especially if we take adequately into account the interaction of the plants and animals in them and the essentially opposite products and requirements of the latter (cf. 17 on methods and instruments for procuring samples).

For an understanding of the relations between the aquatic regions and the saprobiotic zones, we should like to stress here that, for example, a lake deriving oligosaprobiotic character from its plankton and benthos may well contain mesosaprobiotic mud organisms and often does contain them. The same lake may also change its biological picture with the seasons because, e.g., an abundant growth of hydrophyll plants dies off and thus brings mesosaprobiotic elements into the true plankton zone, especially near the banks.

The foundations of the biological evaluation of water find their basis in the proper appreciation of these combinations. Nearly always we must be concerned not only with testing the water but with determining the entire state of a collector.

In the present communication, we have placed the main emphasis on the system and restricted discussion in the text as much as possible. In a more extensive report to be published in the Reports of the Royal Institute for Water Supply and Sewage Disposal, we intend to combine the ecological systems of both plants and animal organisms.

The following brief considerations are intended to serve as a characterization in biological and chemical respect of the principal zones referred to initially.

I - The zone of polysaprobia is characterized chemically by a certain degree of wealth of high-molecular, putrescible and organic substances (protein components and carbohydrates) which enter the collectors in the directly putrescible sewage from cities and agricultural, industrial and other enterprises. A decrease of oxygen content of the water accompanied by reduction manifestations, formation of hydrogen sulphide in the mud and an increase of carbon dioxide often are the chemical sequels of this.

Organisms generally occur in great numbers but with a certain monotony; especially Schizomycetes and (usually bacteriophage) colorless flagellates are frequent. The bacteria developed in standard nutrient gelatine may exceed 1 million per ccm water. Organisms with high oxygen requirements obviously are generally completely absent. Fishes usually avoid remaining in this zone for any length of time.

Plant organisms preferring hydrogen sulphide in this zone may recur in H_2S sources in the oligosaprobiotic zone.

II - The zone of the mesosaprobia is divided into a alpha- and/or beta-saprobiotic section. It generally succeeds the polysaprobiotic zone. In the alpha-section which adjoins the former, self-purification takes place still rather agressively as already mentioned but with the simultaneous occurrence of oxidation manifestations -- in contrast to zone I -- which are conditioned in part by the oxygen production from chlorophyllous plants.

The protein components contained in the water are probably already decomposed down to asparagin, leucine, glycocoll, etc., which results in a qualitative difference from zone I.

In the beta-section, the decomposition products already approach mineralization. Normal, generally nitrate-containing effluents from the trickle fields are most properly included in this zone.

All organisms of the mesosaprobiotic zone usually are resistant to minor action by sewage and its decomposition products. Notable is among other factors the content of the zone of Diatomaceae, Schizophyceae and many Chlorophyceae and some higher plant organisms. Higher and lower animal organisms are also found in a great number of individuals and varieties.

III - The zone of the oligosaprobia is the domain of (practically) pure water. If it was preceded by a self-purification process locally or chronologically, it succeeds the mesosaprobiotic zone and then represents the termination of mineralization. However, we here include also lakes in which the water does not undergo a mineralization process properly speaking. The oxygen content of the water may often remain permanently close to the saturation limit and occasionally even exceed the latter (as a function of the air dissolved in the water). The content of organic nitrogen usually does not exceed 1 mg/lit. The water is generally transparent to a considerable depth, except at times of abundant plant growth. The number of bacteria developed on standard nutrient gelatine is generally low. In contrast to the polysaprobiotic zone, it amounts to only a few hundreds and infrequently thousands of bacteria per ccm water.

Both the plant and animal plankton of our clean country lakes belongs in this zone. We already pointed out that the mud of such waters may have a beta-mesosaprobiotic character.

Further characteristics of the three principal zones will be found in "Ecology of Plant Saprobia".

Catharobia, i.e., i n h a b i t a n t s of perfectly pure water, have here not been listed intentionally because they have nothing or almost nothing to do with the self-purification of any of these waters. We might count inhabitants of pure mountain streams among them (e.g. Planaria alpina Dana) but the aeration and coolness of the water plays a greater role for them on the basis of our present experience than the particular pure quality of the water.

We are probably justified in already pointing out here that the greater part of the animal organisms living in these waters can advance further into contaminated zones than we have been inclined to assume so far, provided they find the required amount of oxygen.

Ecological System of Animal Saprobia

Within the three principal ecological groups, the organisms listed here and which number more than 500, are arranged in accordance with the natural system, except for the fishes. As for the plant saprobia, we have here also based ourselves in the classification of the various animals on our own observations in the open as far as possible. We endeavored to find the centers of optimum growth and development of the organisms especially at locations with graduated self-purification and determined the position in the ecological system on the basis of these observations.

We do not want to fail to point out here that many pertinent data in literature are incomplete. This is due to the fact that until the present time too few different locations had been investigated and that there usually did not exist any chemical analysis which is highly desirable for these purposes. Occasionally an observer unfamiliar with local conditions has great difficulty in arriving at an accurate evaluation of the character of the particular body of water.

Since it was obviously impossible to enumerate all organisms occurring in water and suitable for the present purposes, we have selected those -- by avoiding any overloading with names of the system here as also in the case of the plants -- which are of definite interest for the evaluation of the state and the self-purification of water on the basis of the present investigations. We need not specifically point out that further investigations may result in future additions to the listing.

In spite of this, the present system already forms a relatively complete whole because we have listed sufficient organisms for each zone so that they already afford a thorough characterization.

In looking over the system, it will be noted that the names of Linné and Ehrenberg occur frequently which is a sign that we have utilized for evaluation as far as possible the more frequent and generally known organisms.

We have endeavored to furnish the most complete enumeration of poly- and alpha-mesosaprobiotic organisms because these are the most important (as inhabitants of the locations of intensive self-purification) for the evaluation of the water.

In order to prevent any too severe evaluations of the degree of purity of the water, we have restricted -- while trying to maintain completeness as far as possible -- the groups of the organisms just named as far as possible and have instead pointed out any possible overlapping of the purer zones into the preceding zones.

The colorless flagellates have been taken into account fully in accordance with their frequency and extensive distribution. They are particularly characteristic for the poly- and alpha-mesosaprobiotic zones.

The Chrysomonodales, Cryptomonodales, Euglenales, Peridiniales and (partly) Protococcales, all part of the flagellates, have already been treated in the plant ecology, not because we meant to stress their belonging to the vegetable kingdom but because all oxygen-producing (aerating) organisms should be grouped in one system as far as possible.

The Ciliata have the greatest significance in the evaluation of the degree of contamination of many water courses and especially their contaminating affluents which daily observation has confirmed for us over many years. They have therefore been taken into account particularly, the more so since they can be determined more easily than the small flagellates. Spongiae are in general not very suitable for evaluation of water on the basis of our present investigations although they may be often considerably advanced in their development through nutrient affluents.

Among the Vermes, the limicolus tubificids are of considerable importance for the evaluation of the poly- and alpha-mesosaprobiotic zone whereas others belong more to the zone of pure water. The nematodes, occupying the intermediary position in comparison with them, are important for microscopic analysis. The greater part of the species is of lesser importance for water evaluation on the basis of the present investigations but may play an important role in the consumption and loosening up of mud.

We gathered extensive data on the Rotatoria so that we were able to utilize them sufficiently thoroughly especially in the evaluation of streams in addition to other animal and plant groups.

Although the Bryozoa are widely distributed, they have so far been investigated very little in respect to their suitability for water evaluation.

The greater part of the molluscs have been classified in the group of oligosaprobiotic organisms. This indicates that -- similar to the higher aquatic plants -- most of them are not used very much for the differentiation of the different zones of importance in the characterization of self-purification. However, they are of the greatest importance for the evaluation of the state of water merely by their role as indicators. They may indicate toxic agents by their sudden decay, asphyxiation from lack of oxygen through putrefaction, lack of calcium through their almost complete absence, etc.

Molluscs may also play an important role as scavengers of detritus -- as do the snails as omnivora and vegetarians -- in keeping streams and other bodies of water clean.

As far as possible, Crustaceae have been considered for water investigations by us and utilized in the ecological system. However, they would seem to merit -- especially the Cyclopida -- further study in regard to the interrelation between distribution and water character.

Arachnoidea need be considered for general biological analysis only to a minor degree on the basis of our present investigations. Insect larvae and, in part, the adult insects -- with the exception of the red larvae of Chironomus and others -- play a role in the evaluation of waters only insofar as they do not advance into contaminated zones. When they occur abundantly, as is often the case, their activity in feeding and the many adult insects in their escape from the water have great importance for keeping the latter clean and may also be of considerable value as fish feed by reason of their relative size.

The various species of insect larvae could be taken into consideration only very little in the present state of science because determination of type from the larvae is usually not possible. It becomes necessary to breed the imagoes which has not yet been done on a planned basis for the present purpose either by us or anyone else to judge from the available literature.

At a summary review, most Pisces can be classified under two groups different by nature: the mud fishes often living in purposely fertilized ponds, and the predatory fish. On this basis and in consideration of other particularities of habitat, we have placed part of the fishes in the beta-mesosaprobiotic and the others in the oligosaprobiotic zone. Many fishes, in particular those with greater vital tenacity, also enter the alpha-mesosaprobiotic zone in feeding and come close to the polysaprobiotic zone but seem to prefer the purer zones wherever possible. This would seem to be valid also for their spawn.

Among the Aves, the gulls (especially Larus ridibundus L), crows (especially Corvus cornix L) and ducks (usually Anas boschas L) are noteworthy as scavengers of lumps of sewage and proliferating sewage fungi.

I. Polysaprobia

Rhizopoda

Hyalodiscus limax (Duj.)
" guttula (Duj.)
} both often together with Polytoma and Spirillae; when isolated, also mesosaprobiotic.

Flagellata

Cercobodo longicauda (Duj.) Senn.
=Cercomonas longicauda Duj.
=Dimorpha longicauda (Duj.) Klebs.
=Dimastigamoeba longicauda Klebs., overlaps into alpha-mesosaprobiotic zone.
Oicomonas mutabilis Kent.
Bodo putrinus (Stokes) Lemm.
Trepomonas rotans Klebs.
Hexamitus inflatus Duj.
} tends also to be alpha-mesosaprobiotic.
" crassus Klebs.
" pusillus Klebs.
" fissus Klebs.
" fusiformis Klebs.
} overlaps into alpha-mesosaprobiotic zone.

Ciliata

Paramaecium putrinum Cl. & L.
Vorticella microstoma Ehrbg.
" putrina O.F. Müller

Vermes

Tubifex tubifex (O.F. Müller), when predominant and abundant.

Diptera

Eristalis tenax L., larvae, often in highly contaminated trickle-filled ditches and strongly hydrogen-sulphide-containing storage areas; also in the mesosaprobiotic zone.

II. Mesosaprobia

1. Alpha-mesosaprobiotic

Rhizopoda

Trinema enchelys (Ehrbg.) Leidy.
Diplophrys archeri Barker.
Pamphagus hyalinus Leidy.
" armatus Lauterb.
Cryptodifflugia oviformis Penard.

Flagellata

Ciliophrys infusionum Cienk; frequent inhabitant of contaminated aquaría.
Cercobodo radiatus (Klebs.) Lemn.
=Dimorpha radiata Klebs.
Cercomonas clavata Perty.
" crassicauda Duj.
Oicomona termo (Ehrbg.) Kent.
Monas vivipara Ehrbg.
" vulgaris (Cienk.) Senn.=Monas guttula Ehrbg.
" arhabdomonas (Fisch) H. Meyer.
Anthophysa vegetans (O.F. Müll.) Bütschli., very typical for alpha mesosaprobiotic zone; when colonies die off in pure water, the stems remain.
Amphimonas globosa, Kent
" fusiformis Mez.
Bodo globosus Stein.
" mutabilis Klebs.
" minimus Klebs.
" caudatus (Duj.) Stein.
" saltans Ehrbg., also in the polysaprobiotic zone.
" ovatus (Duj.) Stein
Spongomonas intestinum (Cienk.) Kent, also in the beta-mesosaprobiotic zone.
Dallingeria drysdali Kent, also in the beta-mesosaprobiotic zone.
Pleuromonas jaculans Perty.

Phyllomitus amylophagus Klebs.
Rhynchomonas nasuta (Stokes) Klebs.
Tetramitus descissus Perty
" salcatus Klebs.
" pyriformis Klebs.
" rostratus Perty.
Urophagus rostratus (St.) Klebs.
Trigonomonas compressa Klebs.
Trepomonas agilis Duj., also in the beta-mesosaprobiotic zone.
" steini Klebs.
Menoidium pellucidum Perty.
Astasiopsis distorta (Duj.)
Astasia margaritifera Schmarda = Astasiodes.
Euglenopsis vorax Klebs.
Peranema trichophorum (Ehrbg.) St.
Heteronema tremulum Zach.
" (=Zygoselmis) acus (Ehrbg.) St.
Scytomonas pusilla Stein.
Chilomonas paramaecium Ehrbg., also in the beta-mesosaprobiotic zone.
Spirochaete plicatilis Ehrbg.

Ciliata

Urotricha farcta (Ehrbg.) Cl. & L.
Amphileptus claparedi Stein, possibly also polysaprobiotic.
" carchesii Stein.
Lionotus varsaviensis Wrz.
Loxophyllum meleagris (O.F. Müll.) Duj., also in the beta-mesosaprobiotic zone.
Cyclogramma rubens Perty
(=Nassula Clap. & L. & A.)
Chilodon uncinatus Ehrbg., also in the beta-mesosaprobiotic zone.
Trochilia palustris Stein, also in the beta-mesosaprobiotic zone.
Leucophrydium putrinum Roux.
Glaucoma scintillans Ehrbg.,
also in the beta-mesosaprobiotic zone.
Colpidium colpoda Stein.
Colpoda cucullus Ehrbg.
" parvifrons Cl. & L.
" steini Maupas
} also in the beta-mesosaprobiotic zone.
Loxocephalus granulosus Kent.
Paramaecium caudatum Ehrbg.
Cyclidium glaucoma Ehrbg.
Spirostomum ambiguum Ehrbg., also in the beta-mesosaprobiotic zone.
Stentor coeruleus Ehrbg.
" roeseli Ehrbg., also in the beta-mesosaprobiotic zone.
Gyrocoris oxyura Stein
=Caenomorpha medusula Perty, was also found abundantly in stagnant hydrogen sulphide-containing river water in which oxygen could not be demonstrated with the Winkler method.
Urostyla weissei St. = U. multipes (Cl. & L.),
possibly also polysaprobiotic.
Gastrostyla mystacea (St.)
Oxytricha fallax Stein.
" pellionella Ehrbg.
Stylonychia mytilus Ehrbg., also in the beta-mesosaprobiotic zone.
Gerda glans Lachm.
Vorticella convallaria Ehrbg.
Carchesium lachmanni Kent.
Epistylis coarctata, Cl. & L.
" plicatilis Ehrbg., also in the beta-mesosaprobiotic zone.

Suctoria

Podophrya carchesii Cl. & Lachm.
" fixa Ehrbg., also in the beta-mesosaprobiotic zone.

Vermes

Enchytraeus humicultor Vejd.
Pachydrilus pagenstecheri (Ratz.) Vejd.
Lumbriculus variegatus (Müll.) also in the beta-mesosaprobiotic zone.
Limnodrilus udekemianus Clap.
" hoffmeisteri Clap.
Tubifex tubifex (Müll.), overlaps into the polysaprobiotic zone
(cf. the latter) and beta-mesoprobiotic zone.
Lumbricillus lineatus (Müll.), advances from the sea to contaminated brackish and/or sweet water.
Psammoryctes barbatus Vejd.
Dero limosa Leidy.
Aeolosoma quaternarium Ehrbg.
Lumbricus rubellus Hoffm.
Monohystera macrura De Man, also in the beta-mesosaprobiotic zone.
Tripyla setifera Butschli
Trilobus gracilis Bast.
Plectus tenuis Bast.
Diplogaster rivalis (Leyd.).

Rotatoria

Rotifer vulgaris Schrank, also in the beta-mesosaprobiotic zone.
" actinurus Ehrbg., occasionally polysaprobiotic; occurs in water enriched with hydrogen sulphide and poor in oxygen as demonstrated by the Winkler method.
Callidina elegans Ehrbg., and other varieties.
Triarthra longiseta Ehrbg., often abundant in contaminated village ponds and collectors which receive sewer outflow.
cf. var limnetica.
Hydatina senta Ehrbg., occurs isolated also in the weak mesosaprobiotic zone.
Diglena biraphis Gosse
" caudata Ehrbg.
} also in the beta-mesosaprobiotic zone.
Diplax compressa Gosse.
" trigona Gosse.
Diplois daviesae Gosse.
Colurus bicuspidatus Ehrbg; isolated, also in the beta-mesosaprobiotic zone.
Brachionus angularis Gosse, also in the beta-mesosaprobiotic zone.
" militaris Ehrbg., also in the beta-mesosaprobiotic zone.

Mollusca

Sphaerium (=Cyclas) corneum L., occurs abundantly in the Spree River downstream from the Berlin emergency outlets; very resistant to organic sewage; also in beta-mesosaprobiotic mud.

Crustacea

Asellus aquaticus (L.) Ol., when in large amounts and well developed; often between putrefying Spherotilus on which it may feed.

Neuroptera

Sialis lutaria L., larvae, very resistant, often in very much dirt; also in mud of Lake Lucerne and elsewhere.

Hemiptera

Velia currens Febr. Very resistant against contamination.

Diptera

Chironomus plumosus L., larvae, abundant occurrence very typical for this region; also in the poly- and beta-mesosaprobiotic zone. This species with its red larvae is a collective species.
" motitator (L.), also in the beta-mesosaprobiotic zone.
Tanypus monilis (L.), also in the beta-mesosaprobiotic zone.
Caenia fumosa Stenh., larvae, imago along the edges of purine ditches.
Ptychoptera contaminata L., larvae; often associated with Beggiatoa and Euglena virdis.
Psychoda phalaenoides (L.), larvae
" sexpunctata Curtis.
" =Ps. phalaenoides Meigen, larvae.
Stratiomys chamaeleon L., larvae.

2. Beta-mesosaprobiotic

Rhizopoda

Amoeba brachiata Duj.
" verrucosa Ehrbg.
" radiosa Ehrbg. =Dactylosphaerium.
Pelomyxa palustris Greff, also alpha-mesosaprobiotic.
Cochliopodium bilimbosum Leidy.
" pellucidum (Arch.) Hertw. & Less., also alpha-mesosaprobiotic.
Arcella vulgaris Ehrbg., also alpha-mesosaprobiotic.
Centrophyxis aculeata (Ehrbg.) St.
Euglypha alveolata Duj.
Platoum stercoreum (Cienk.)
Pamphagus mutabilis Bailey.

Heliozoa

Actinophrys sol Ehrbg., also alpha-mesosaprobiotic.
Actinosphaerium eichhorni (Ehrbg.) also alpha-mesosaprobiotic.
Spaerastrum fockei (Arch.).
Clathrulina elegans Cienk., also alpha-mesosaprobiotic.

Flagellata

Mastigamoeba aspera F.E. Sch.
" invertens Klebs.
" limax Moroff.
" polyvacuolata Moroff.
Eucomonas socialis Moroff.
Spaeroeca volvox Lauterborn.
Bodo celer Klebs.
" rostratus (Kent) Klebs.
" uncinatus (Kent) Klebs.
" repens Klebs.
Pleuromonas jaculans Perty.
Menoidium falcatum Zach.
Phialonema cyclostomum St.=Urceolus cyclostomus (St.) Mereschk.
Anisonema acinus Duj.
Entosiphon sulcatum (Duj.) St.
Chilomonas paramaecium Ehrbg.; also alpha-mesosaprobiotic.

Ciliata

Urotricha lagenula (Ehrbg.).
Enchelys pupa Ehrbg.
" silesiaca Mez.
Prorodon farctus (Cl. & L.).
" platyodon Blochm.
Lagynus elegans (Engelm.) tends to be also oligosaprobiotic.
Coleps hirtus Ehrbg., also alpha-mesosaprobiotic.
Didinium nasutum Stein.
Disematostoma buetschlii Lauterb.
Loxophyllum armatum Cl. & L.
" (= Lionotus) fasciola Cl. & L.; also alpha-mesosaprobiotic.
" lamella Cl. & L.
Trachelophyllum lamella (L. F. M.).
" pusillum Clap.
Trachelius ovuum Ehrbg.
Loxodes rostrum Ehrbg.
Nassula elegans Ehrbg.
" ornata Ehrbg.
Chilodon cucullulus Ehrbg., also alpha-mesosaprobiotic.
Opisthodon niemeccensis Stein.
Dysteropsis minuta Roux.
Frontonia acuminata (Ehrbg.) Cl. & L.
Chasmatostoma-reniforme Engelm.
Uronema griseolum (Mps.).
" marinum Duj.
Cinetochilum margaritaceum Perty.
Paramaecium bursaria (Ehrbg.) Focke.
" aurelia (O.F. Müll.) also alpha-mesosaprobiotic.
Urocentrum turbo Ehrbg.
Lembadion bullinum (O.F. Müll.) Perty.
Pleuronema chrysalis (Ehrbg.) Stein.
Balantiophorus minutus Schew., tends to be also oligosaprobiotic.
Blepharisma lateritium (Ehrbg.) Stein.
Metopus sigmoides (O.F.M.) Cl. & L., also alpha-mesosaprobiotic.

" contortus Levander.
" pyriformis Levander.
Plagiopyla nasuta Stein.
Spirostomum teres Cl. & L.
Condylostoma vorticella Ehrbg., tends to be also oligosaprobiotic.
Bursaria truncatella O.F. Müll.
Tylacidium truncatum Schew.
Climacostomum virens Stein.
Stentor polymorphus Ehrbg., tends to be also oligosaprobiotic.
" igneus Ehrbg.
" niger Ehrbg.
Halteria grandinella (O. F. Müll.).
Tintinnidium fluviatile (St.); tends to be also oligosaprobiotic.
Uroleptus musculus Ehrbg.
" piscis (Ehrbg.)
Stylonychia mytilus Ehrbg.
Euplotes patella Ehrbg.
" charon Ehrbg.
Aspidisca costata Stein
" lynceus Ehrbg.
} also alpha-mesosaprobiotic.
Astylozoon fallax Engelm.
Vorticella campanula Ehrbg.
" patellina Ehrbg.
" citrina Ehrbg.
Carchesium epistylis Cl.
Zoothamnium arbuscula Ehrbg.
Epistylis umbellaria Lachm. and other species.
Cothurnia crystallina Ehrbg.

Suctoria

Sphaerophrya pusilla Cl. & L. and other species which are in part not yet accurately determined.
Podophrya quadripartita Cl. & L.
Acineta grandis Kent.

Spongiae

Ephydatia muelleri (Lieberkuhn)
" fluviatilis (L.)
Euspongilla lacustris (L.)
Spongilla fragilis Leidy
} also overlap into adjacent zones; very little suitable for water evaluation as far as is known now.

Hydroidea

Hydrae on Lemnae occasionally also in this region; cf. oligosaprobiotic zone.

Vermes

Rhynchelmis limosella Hoffm.; isolated; also alpha-mesosaprobiotic.
Eiseniella tetraedra (Sav.). amphibian
Criodrilus lacuum Hoffm.
Nephelis vulgaris Moq.-Tand, overlaps
Clepsine bioculata (Bergm.)
" sexoculata (Bergm.)
} tends to be also oligosaprobiotic.
Naïs elinguis Müll., also alpha-mesosaprobiotic.
Stylaria lacustris (L.)
Haemopis sanguisuga (Bergm.) = Aulostomum gulo Moq.-Tand.
Polycelis nigra (Müll.) Ehrbg.
Dendrocoelum lacteum Oerst.
Cercariae with forked rudder tail (in plankton).

Rotatoria and Gastrotricha

Floscularia atrochoides Wierz.
Atrochus tentaculatus Wierz.
Melicerta ringens Schrank.
Conochilus unicornis Rousselet.
Philodina roseola Ehrbg., also alpha-mesosaprobiotic.
" erythrophthalma Ehrbg.
" megalotrocha Ehrbg.
Rotifer tardus Ehrbg.
" bulgaris Schrank, vgl., also alpha-mesosaprobiotic.
" macrurus Ehrbg.
Asplanchna priodonta Gosse, tends to be also oligosaprobiotic.
Synchaeta tremula Ehrbg., tends to be also oligosaprobiotic.
" pectinata Ehrbg. tends to be also oligosaprobiotic.
Polyarthra platyptera Ehrbg. tends to be also oligosaprobiotic.
Triarthra longiseta var limnetica (Zach) = Tr. thranites Skor.
" mystacina Ehrbg.
Taphrocampa selenura Gosse.
Proales tigridia Gosse.
Furcularia gracilis Ehrbg., also alpha-mesosaprobiotic.
" forficula Ehrbg.
" gibba Ehrbg.
" reinhardti Ehrbg., occasionally associated with Stentor coeruleus.
Diglena catellina Ehrbg., also alpha-mesosaprobiotic.
" forcipata Ehrbg., "
Dinocharis pocillum Ehrbg., tends to be also oligosaprobiotic.
" tetractis Ehrbg., "
Scaridium longicaudum Ehrbg.
Stephanops unisetatus Collins.
Diaschiza semiaperta Gosse, also alpha-mesosaprobiotic.
" tenuior Gosse.
Salpina macracantha Gosse.
" mucronata Ehrbg., also alpha-mesosaprobiotic.
Euchlanis triquetra Ehrbg.
Cathypna luna Ehrbg.
Monostyla lunaris Ehrbg.
Lepadella ovalis Ehrbg. also alpha-mesosaprobiotic.
Pterodina patina Ehrbg., saprobiotic.
Pompholyx sulcata Hudson.
Noteus quadricornis Ehrbg.
Brachionus militaris Ehrbg., also alpha mesosaprobiotic.
" pala Ehrbg. = B. pala-amphiceros Plate
" urceolaris Ehrbg.
" rubens Ehrbg.
" bakeri Ehrbg.
" angularis Gosse, also alpha mesosaprobiotic.
Anuraea aculeata Ehrbg.
" cochlearis Gosse
} tends also to be oligosaprobiotic.
Notholca striata Ehrbg.
" acuminata Ehrbg.
" labis Gosse.

Lepidoderma rhomboides Stokes
Dasydytes longisetosum Metschnikoff
" zelinkai Lauterborn.
" saltitans Stokes

Bryozoa

Plumatella repens (L.).
" (Alcyonella) fungosa (Pall.).

Mollusca

Limnaea (=Gulnaria) auricularia L., characterized by resistance to some chemical sewage.
" auricularia f. ampla Hartm.
" ovata Drap.
Valvata piscinalis Müll.
Vivipara contecta Millet = V. vera v. Frauenfeld, occurs abundantly also in foul-smelling mud.
" fasciata Müll.
Bythinia tentaculata (L.) Gray, also downstream from sewer outlets.
Lithoglyphus naticoides Ferussac in the Rhine River frequently associated with L. auricularia.
Neritina fluviatilis (L.). the egg capsules were frequently found on the shells of live paludines downstream from sewer outlets.
Unio tumidus Phil.
Sphaerium (=Cyclas) rivicolum Leach }
" moenanum Kobelt } tends to be also oligosaprobiotic
Calyculina lacustris Müll.

Crustacea

Asellus aquaticus (L.) Ol., also alpha-mesosaprobiotic.
Gammarus fluviatilis Rös., also downstream from sewer outlets and also feeds on Spherotilus.
Cyclops strenuus S. Fischer, also alpha-mesosaprobiotic }
Cyclops leuckarti Claus. }
Cyclops brevicornis Claus, also alpha-mesosaprobiotic } with their development stages
Cyclops fimbriatus Fischer }
Cyclops phaleratus Koch. }
Diaptomus castor Jurine.
Canthocamptus staphylinus (Jur.), also in drinking-water sand-filters.
Cypridopsis vidua (O.F. Müll.).
Cypria ophthalmica Jurine.
Candona candida (Müll.) and other species
Daphnia pulex Degeer, also alpha-mesosaprobiotic.
" magna Strauss, "
" schaefferi Baird, "
" longispina O.F. Mull.
Moina rectirostris (F. Leydig).
Chydorus sphaericus (O.F. Müll.).
Pleuroxus excisus Schödler.

Hydrachnidae

Limnesia maculata (Müller) Bruzelius.
Arrhenurus bicuspidator Berl., also with Peranema and Euglena viridis.

Tardigrada

Macrobiotus macronyx Duj.

Neuroptera

Anabolia laevis Zett., larvae.
Molanna angustata Curtis, larvae.
Hydorpsyche angustipennis Curtis and larvae of some not accurately determined varieties.
Oxyethira costalis Curtis, larvae.

Diptera

Culex annulatus Fabr., and other species; larvae non-demanding.
Chironomus-larvae of a light yellow but not red color.
Ceratopogon-larvae of not accurately determined varieties.
Simulium ornatum Meig. }
" reptans L. } also alpha-mesosaprobiotic.

Pisces (the most resistant representatives appear first)

Cobitis fossilis (L.).
Carassius carassius (L.).

Tinca tinca (L.).
Cyprinus carpio L.
Anguilla vulgaris Flem., with the exception of the youth stages.
Rhodeus amarus Bl.
Gasterosteus aculeatus L.
Leucaspius delineatus v. Sieb.
Alburnus lucidus Heck.

Amphibia

Rana esculenta L. }
" fusca Rösel } spawn and tadpoles in part not very sensitive

III. Oligosaprobia

Rhizopoda

Amoeba proteus Leidy = A. princeps Ehrbg.
Difflugia globulosa Duj., also in the beta-
" pyriformis Perty, mesosaprobiotic zone.
" urceolata Cart.
" acuminata Ehrbg.
" corona Wallich, also in the beta-mesosaprobiotic zone.
" hydrostatica Zach.
" limnetica Levander and other species.
Lecquereusia spiralis (Ehrbg.)
Euglypha globosa (Cart.) = Sphenoderia lenta Schlumbg.
Cyphoderia ampulla (Ehrbg.) Leidy.
Cyphidium aureolum Ehrbg.
Microgromia socialis Hertw. & Less., also in the beta-mesosaprobiotic zone.

Heliozoa

Rhaphidiophrys pallida F.E. Sch., also in the beta-mesosaprobiotic zone.
Acanthocystis turfacea Cart., also in the beta-mesosaprobiotic zone.

Flagellata

Dimorpha alternans Klebs.
Bicoeca lacustris J.-Cl.
" oculata Zach.
Diplosiga frequentissima Zach.
— also in the beta-mesosaprobiotic zone.

Ciliata

Holophrya ovum Ehrbg., also in the beta-mesosaprobiotic zone.
Rhabdostyla ovum Kent.
Lacrymaria olor Ehrbg.
Trachelius elephantinus Svec.
Dileptus trachelioides Zach.
Ophryoglena atra Lieberk.
Frontonia acuminata (Ehrbg.)=O. acuminata & atra Ehrbg.
Strombidium adhaerens Schew. =Str. sulcatum Cl. & L.
" turbo Cl. & L., also in the beta-mesosaprobiotic zone.
Codonella lacustris Ents., also in the beta-mesosaprobiotic zone.
Oxytricha ferruginea Stein.
Stylonychia pustulata Ehrbg., also in the beta-mesosaprobiotic zone.
" histrio (O.F.Müll.).
Vorticella nebulifera Ehrbg.
Carchesium polypinum Ehrbg., also in the beta-mesosaprobiotic zone.
Ophrydium versatile Ehrbg.

Suctoria

Most representatives of this group are probably mesosaprobiotic except for Staurophyra elegans Zach.

Hydroidea

Cf. beta-mesosaprobiotic zone.
Cordylophora lacustris Allm.; lives mainly in brackish water.
Hydra vulgaris Pall. = H. grisea L.
" oligactis Pall.= fusca L.
" polypus L.
" viridis L.

Vermes

Haplotaxis gordioides (G.L. Hartm.) =Phreoryctes menkeanus Hoffm.
Chaetogaster diaphanus (Gruith.), also in the beta-mesosaprobiotic zone.
Gordius aquaticus Duj.
Polycelis cornuta O. Schm.
Planaria gonocephala Dug.
Vortex pictus O. Schm., also in the beta-mesosaprobiotic zone.

Rotatoria and Gastrotricha

Floscularia cornuta Dobie.
Tubicolaria najas Ehrbg.
Asplanchna brightwelli Gosse
Sacculus viridis Gosse, also in the beta-mesosaprobiotic zone.
Triarthra breviseta Gosse
Rattulus capucinus Wierz. et Zach.=Mastigocerca hudsoni Lauterb., also in the beta-mesosaprobiotic zone.
Diurella stylata Eyf. =Rattulus bicornis Western.
Salpina brevispina Ehrbg.
Euchlanis dilatata Ehrbg., also in the beta-mesosaprobiotic zone.
Pompholyx complanata Gosse.
Anuraea hypelasma Gosse.
Notholca foliacea Ehrbg., also in the beta-mesosaprobiotic zone.
" longispina Kellicott
" scapha Gosse.
Gastroschiza flexilis Jaegersk, also in the beta-mesosaprobiotic zone.
Ploesoma truncatum Levander, also in the beta-mesosaprobiotic zone.
Gastropus stylifer Imhof, also in the beta-mesosaprobiotic zone. =Hudsonella pygmaca (Calm.).
Anapus ovalis Bergendal
" testudo Lauterb.
— also in the beta-mesosaprobiotic zone.
Schizocerca diversicornis Dod., also in the beta-mesosaprobiotic zone.
Pedalion mirum Hudson
Ichthydium podura O.F. Müller
Chaetonotus maximus Ehrbg., occasionally also beta-mesosaprobiotic; frequent in dry wells; seems little sensitive to H_2S.
Chaetonotus larus O.F. Müller, occasionally also beta-mesosaprobiotic.

Bryozoa

Cristatella mucedo Cuv.
Fredericella sultana (Blumenb.) Gerv.
Paludicella ehrenbergi van Ben.

Mollusca

Limnaea stagnalis (L.) Lam.
" palustris Müll.
" peregra Müll.
— also in the beta-mesosaprobiotic zone.
Amphipeplea glutinosa Müll.
Physa fontinalis (L.) Drap.
" acuta Drap.
Aplexa hypnorum L.
Planorbis corneus (L.)Pfeiff.
— also in the beta-mesosaprobiotic zone.
" marginatus Drap.
" carinatus Müll. and other kinds.
Ancylus fluviatilis Müll.
" lacustris L.
— also in the beta-mesosaprobiotic zone.
Anodonta mutabilis Cless. Some varieties are very resistant.
Margaritana margaritifera L.
Unio pictorum L., often resistant.
" batavus Lam.
Pisidium amnicum Müll.
" fossarinum Cless.

Dreissensia polymorpha Pallas, especially typical for this zone. larvae planktonic.

Crustacea

Astacus fluxiatilis Fabr.
Gammarus pulex (L.)De Geer.
Niphargus puteanus C.L. Koch.
Cyclops viridis Jur.
" albidus Jur.
" serrulatus Fischer, also in the beta-mesosaprobiotic zone.
" bicuspidatus Claus.
" fuscus Jur.
" oithonoides Sars.
Diaptomus gracilis Sars.
" graciloides Lilljeborg.
" laciniatus Lillj.
Eurytemora velox (Lillj.).
Canthocamptus minutus Claus. } also in the beta-mesosaprobiotic zone.
Cypris virens Jurine).
" incongruens (Ramdohr)
Sida cristallina (O.F. Müll.).
Diaphanosoma brachyurum (Liévin).
" leuchtenbergianum S. Fischer.
Holopedium gibberum Zaddach.
Daphnia hyalina Leydig with subspecies galeata Sars
" (Hyalodaphnia) cucullata G. O. Sars =kahlbergiensis Schoedler.
Scalopholeberis mucronata (O.F. Müll.).
Simocephalus vetulus (O.F. Müll.) Schoedler.
Ceriodaphnia reticulata (Jur.). also in the beta-mesosaprobiotic zone.
Bosmina longirostris (O.F. Müll.); P.E. Müll. & var. cornuta Jur., also in the beta-mesosaprobiotic zone.
" coregoni Baird.
" " var. gibbera Schoedler.
Acroperus harpae Baird.
Leidigia quadrangularis (Leydig); also in the beta-mesosaprobiotic zone.
Lynceus (Alona) guttatus (Sars.); also in the beta-mesosaprobiotic zone.
" costatus (Sars.); and other species.

Bythotrephes longimanus Leydig.
Leptodora kindti (Focke).

Argyronetidae

Argyroneta aquatica Cl.

Hydrachnidae

Most representatives belong in this zone.
Atax crassipes O.F. Müll. (Bruzelius).
Neumania spinipes Müll.
Curvipes nodatus Müll.
" rufus C.L. Koch.
Hygrobates nigro-maculatus Lebert.
Limnochares holosericea Latreille.

Orthoptera. Larvae.

Libellula depressa L., and other species.
Aeschna grandis L.
Calopteryx virgo L., also in the beta-mesosaprobiotic zone.
Agrion puella L.
Ephemera vulgata L.
Polymytarcis (Palingenia) virgo Ol.
Prosopistoma foliaceum Fourcroy
Baetis species
Heptagenia (Ecdyurus) fluminum Pict.
Clōe diptera L., also in the beta-mesosaprobiotic zone.
Perla bicaudata L.
" nubecula Newm.
Taeniopteryx trifasciata Pict.
Nemura variegata Oliv.

Neuroptera

Phryganea striata L., larvae.
" grandis L., "
Sericostoma, larvae of different species; also beta-mesosaprobiotic.
Brachycentrus subnubilus Curt.; also in the beta-mesosaprobiotic zone.
Leptocerus annulicornis Steph.
Rhyacophila vulgaris Pict.
Hydroptila sparsa Curt.

Hemiptera

Hydrometra lacustris L. } not very suitable for water evaluation
" rufoscutellata Cuv.
Limnobates stagnorum Cuv.
Nepa cinera L., rather sensitive to lack of oxygen
Ranatra linearis L., also in the beta-mesosaprobiotic zone.
Aphelocheirus aestivalis Fabr.
Corixa striata L., appears with lack of oxygen under ice first at the "Wuhnen" (colloquial term, possibly meaning hole?).
Notonecta glauca L., somewhat less sensitive to lack of oxygen than Corixa.

Diptera

Corethra plumicornis Fabr., larvae very resistant.

Coleoptera

Dytiscus marginalis L., larvae and beetles; able to follow prey into mesosaprobiotic zone like other predators.
Acilius sulcatus L., larvae and beetles.
Colymbetes fuscus L., larvae and beetles.
Agabus bipustulatus L., larvae and beetles.
Gyrinus natator L., larvae and beetles, not very suitable for water evaluation.
Hydrophilus piceus L., larvae and beetles.

Pisces (the most sensitive representatives are listed first).

Gasterosteus pungitius L.
Esox lucius L.
Lota vulgaris Cuv.
Gobio fluviatilis Cuv.
Scardinius erythropthalmus L.
Blicca bjōrkna L.

Lucioperca sandra L.

Acerina cernua L.
Idus melanotus Heck. & Kn.
Abramis brama L.

Leuciscus rutilus L.
Perca fluviatilis L.
Trutta fario L.

Amphibia

Triton cristatus Laur.
" taeniatus Schneid.

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VALUE OF THE BOTTOM SAMPLER IN DEMONSTRATING THE EFFECTS OF POLLUTION ON FISH-FOOD ORGANISMS AND FISH IN THE SHENANDOAH RIVER

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IN THE PAST several years legislation and activity directed toward the control and abatement of stream polution have greatly increased. Numerous States have passed legislation forming water commissions, water-control boards, or other groups or committees to deal with stream pollution within their borders. Some States have formed interstate agencies to deal with activities in a particular river basin. The passage of Public Law 845 greatly increased activities from a national viewpoint.

All these groups have at sometime or another been concerned with stream surveys to determine extent or degree of pollution. Many groups have worked on this problem and have come up with varied answers. Some have set arbitrary standards of cleanliness, below which no body of water would be allowed to degrade. Others have classified streams into groups (A, B, C, D, etc.) depending on usage and have set standards of cleanliness to be maintained in each class. Still others have set no standards but have treated each pollution problem separately and have had a board to decide the degree of pollution that would be allowed. Unfortunately, little or no consideration has been given to fish or wildlife in many of these surveys or classifications. For many years sportsmen's groups have been fighting for clean streams, and these groups have been instrumental in causing the enactment of much of the constructive pollution legislation. Yet, when pollution is discussed at various meetings and standards are set for streams, practically nothing is heard about what aquatic life (other than bacteria) is in, or should be maintained in a stream.

For a great many streams there is a wealth of information as to the coliform bacteria count, the biochemical oxygen demand, total solids, color, odor, and other factors; but there is very little information as to what fish or fish-food organisms may be present. True, most of these pollution surveys have been made from the standpoint of public health or for municipal or industrial water supplies--which are, of course, very important. But why not include in these surveys some data as to the effects of pollution on normal aquatic life?

Requirements for water to drink or to operate an industry may be vastly different from the requirements for the maintenance of fish and aquatic life. Water from an open sewer would certainly be unfit to drink but, if not in such excessive quantity as to use all the oxygen in the receiving stream, may even have a beneficial effect (through fertilizer values) on aquatic life. Water suitable for industrial use may have small quantities of some toxic substance which would make that water deadly to aquatic life.

Aquatic life in streams may be depleted generally in four ways: (1) lack of dissolved oxygen, (2) too high or too low hydrogen-ion concentration, (3) smothering effect of silt or other fine material, (4) the presence of definitely toxic substances. In general, most pollution surveys would demonstrate the first two of these conditions. Dissolved oxygen and pH are standard tests used in pollution surveys, and the requirements of most aquatic animals are known. The third may show up in observations or from turbidity determinations. The fourth condition would become apparent only through elaborate chemical tests and a knowledge of the toxicity of numerous substances to the various aquatic animals.

Simple methods of determining the effects of the third and fourth factors are based upon use of a Surber (1937) square-foot bottom sampler (figure 1) in gravel and rubble, and Ekman or Peterson dredges in mud or silt. Stream bottoms are normally the habitat for numerous aquatic insect larvae and other aquatic animals. These forms may include the larvae of May flies (Ephemerida), stone flies (Plecoptera), dragon-flies (Anisoptera), damsel flies (Zygoptera), midge flies and crane flies (Diptera), caddis flies (Trichoptera), dobson flies (Neuroptera), and other aquatic animals such as water beetles (Coleoptera), aquatic earthworms (Oligochaeta), crayfish and shrimp (Crustacea), and snails and clams (Mollusca). These are the principal fish-food organisms. Square foot bottom samples taken in riffles above and below sources of pollution show immediately the approximate quantity and the types of fish-food organisms present. Without sufficient quantities of these animals, fish soon disappear for lack of food, whether they can survive in the water or not.

Though all of the physical, chemical, and bacteriological determinations normally used in any stream evaluation are quite important, there is frequently a definite lack of biological determination to show the actual impact of pollution on aquatic life in the stream. This has been forcibly pointed out by Beatty (1947). Ellis and Westfall (1946) and Hart, Doudoroff, and Greenbank (1945) established uniform bioassays or toxicity experiments which could be used to show toxicity levels of various chemicals and wastes for fishes. Though such tests are very useful, there may be great differences between laboratory toxicity tests and actual conditions in streams. Other workers, including Platner (1946), Wiebe (1928), and Ellis (1940), used Peterson dredges and bottom samplers of various kinds to determine the biological impact of pollution.

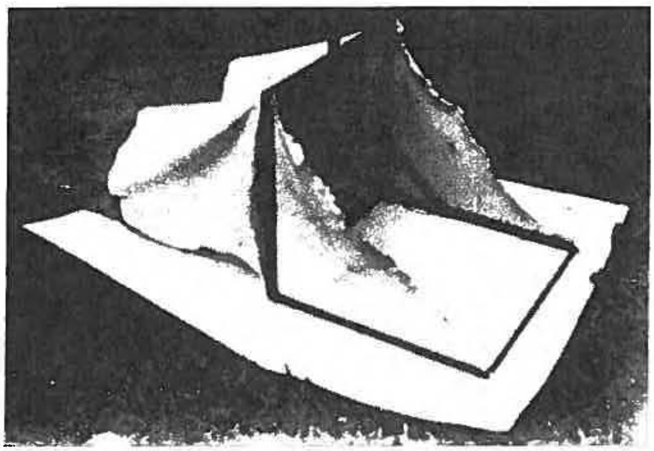


Figure 1 - Surber square-foot bottom sampler.

Methods for the collection and microscopical examination of plankton have been known and used for many years. Many workers, including Lackey (1940), McGauhey (1942), and Purdy (1930), have applied these methods to pollution studies, in which certain types of protozoan plankton and other microscopic organisms were used as indicators of stream pollution.

In a study of pollution of the Coeur D'Alene River, Ellis (1940) called attention to the presence of large numbers of bottom animals, such as caddis-fly larvae and stone-fly and May-fly nymphs, in riffle areas above sources of pollution -- and their complete absence below these sources. Surber (1939) used a square-foot bottom sampler of a new, compact design in sampling four eastern smallmouth-bass streams to determine the fish-food organisms present. This work led to the use of this bottom sampler in pollution studies in the Shenandoah River.

PURPOSE OF INVESTIGATIONS

The Shenandoah River was for a long time the favorite fishing ground of numerous residents of northern Virginia and the eastern panhandle of West Virginia. In fact, this river was so noted as a smallmouth-bass stream that sportsmen were attracted from all over the eastern United States to try their luck at catching the elusive bass. In 1940, a large corporation, the American Viscose Company, began operations at Front Royal, Virginia, on the South Fork of the Shenandoah just above the confluence with the North Fork. Though a clean stream was promised the sportsmen of this section, it was only a short time until fishing in the main Shenandoah had declined considerably. Numerous dead fish were seen in the river during the winter of 1942-43. Sportsmen became alarmed and called upon the Fish and Wildlife Service to determine the condition of the river. Bottom samples taken above and below the Viscose plant showed more than 99 percent decrease in bottom animals 30 miles below the plant, as compared with the number immediately above. This fact was reported to the Virginia Commission of Game and Inland Fisheries in August 1943, but little could be done because of very weak pollution laws. Further fish kills were observed in the winters of 1943-44 and 1944-45, when sport fishing had practically ceased to exist on the main river. About this time, Izaak Walton League chapters were formed in Winchester and Berryville, Virginia, with the clean-up of the Shenandoah River their main objective. These and other nearby chapters sponsored an investigation to determine sources and degree of pollution and its effects on aquatic life in the river: the facts obtained in this study were to be used in making the general public aware of existing conditions. This study was started in June 1947 and was continued throughout the summer. This survey was continued through 1948 by the Fish and Wildlife Service from its Fishery Station at Leetown, West Virginia. Investigations are still under way. This paper is not a complete report of work on the Shenandoah but is undertaken at this time to show certain correlations of numbers and types of bottom animals to pollution, and to show the desirability of using the Surber bottom sampler more widely as a tool in stream pollution surveys.

DESCRIPTION OF RIVER

The Shenandoah River (figure 2) rises in the mountains of northern Virginia, the North Fork in the Allegheny Mountains and the South Fork in the Blue Ridge. Massanutten Mountain separates the two forks. Each fork, fed intermittently by mountain streams and limestone springs, flows a distance of some 150 miles through fertile limestone valleys to Front Royal, Virginia. From the confluence of the forks at Front Royal, the main Shenandoah flows north about 60 miles along the foot of the Blue Ridge Mountains, entering the Potomac River at Harpers Ferry, West Virginia. The lower 20 miles of the river are in West Virginia.

This river is normally a clear, fast-flowing, fertile stream. Extensive riffle areas and limestone ledges serve to make ideal food and cover conditions for fish.

Surber, comparing the Shenandoah River (main stream) with other smallmouth-bass streams in this area (1939), found the growth of bass to be very rapid: the bass reached legal length (10 inches) in 2 to 3 years. Food conditions were reported to be excellent, as there was an abundance of forage fish and bottom animals.

Prior to 1940, the whole Shanandoah River system was considered a mecca for fishermen. Residents of

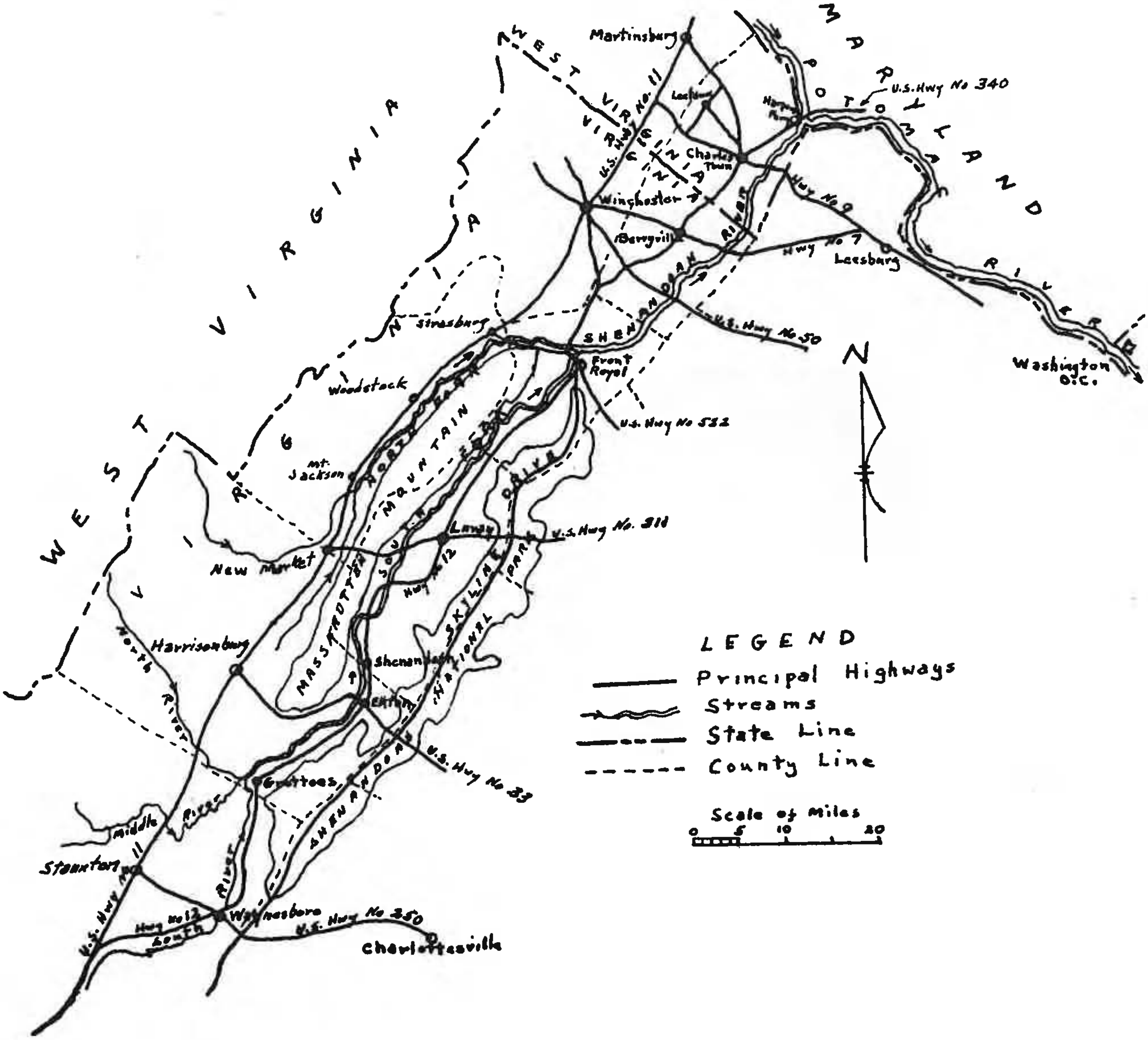


Figure 2 - The Shenandoah River System.

this area claim that as a smallmouth-bass stream it could not be surpassed. Excellent fishing occurred in practically all of the river. The principal species taken were smallmouth bass, largemouth bass, yellowbelly sunfish, channel catfish, carp, suckers, and crappie.

POLLUTION IN THE SHENANDOAH RIVER SYSTEM

Preliminary surveys disclosed no serious sources of pollution (from the fishery standpoint) in the North Fork. Several small towns (Woodstock, Strasburg, and others) discharged raw sewage into the river, but the dilution factor was such that there were no detrimental effects to aquatic life; so the North Fork was not included in this survey.

Three streams--South River, Middle River, and North River--meet just above Port Republic, Virginia, to form the South Fork of the Shenandoah. At Waynesboro, South River receives a serious load of pollution from industries and sewage from the town itself. Fish kills have been reported to the Virginia Game Commission several times. At present, the Virginia Water Control Board is making a study of this part of the river. Owing to this and to the fact that this portion of the river was not considered important for sport fishing, it was not included in this investigation. The remainder of the Shenandoah River system was included (figure 3).

Preliminary bottom samples showed no apparent effect on aquatic life from the sewage of the four towns; so this study was confined primarily to the effect of industrial wastes from the Merck Chemical Company and the American Viscose Corporation plants.

It was suspected that the Viscose effluent contained one or more substances that were deadly to aquatic animals and that this material persisted in the water for a considerable distance downstream. From a study of materials used at the Viscose Corporation plant in

Figure 3 - Study stations and sources of pollution.

Sources of pollution:

A -- The Merck Chemical Company, Elkton, Virginia: manufactures streptomycin, vitamin B_1, and other chemicals; empties wastes (nature of which is not definitely known) directly into the South Fork of the Shenandoah River; has facilities for waste treatment.

B -- Domestic sewage from the town of Elkton, Virginia: population, 1,500; untreated wastes empty directly into the river.

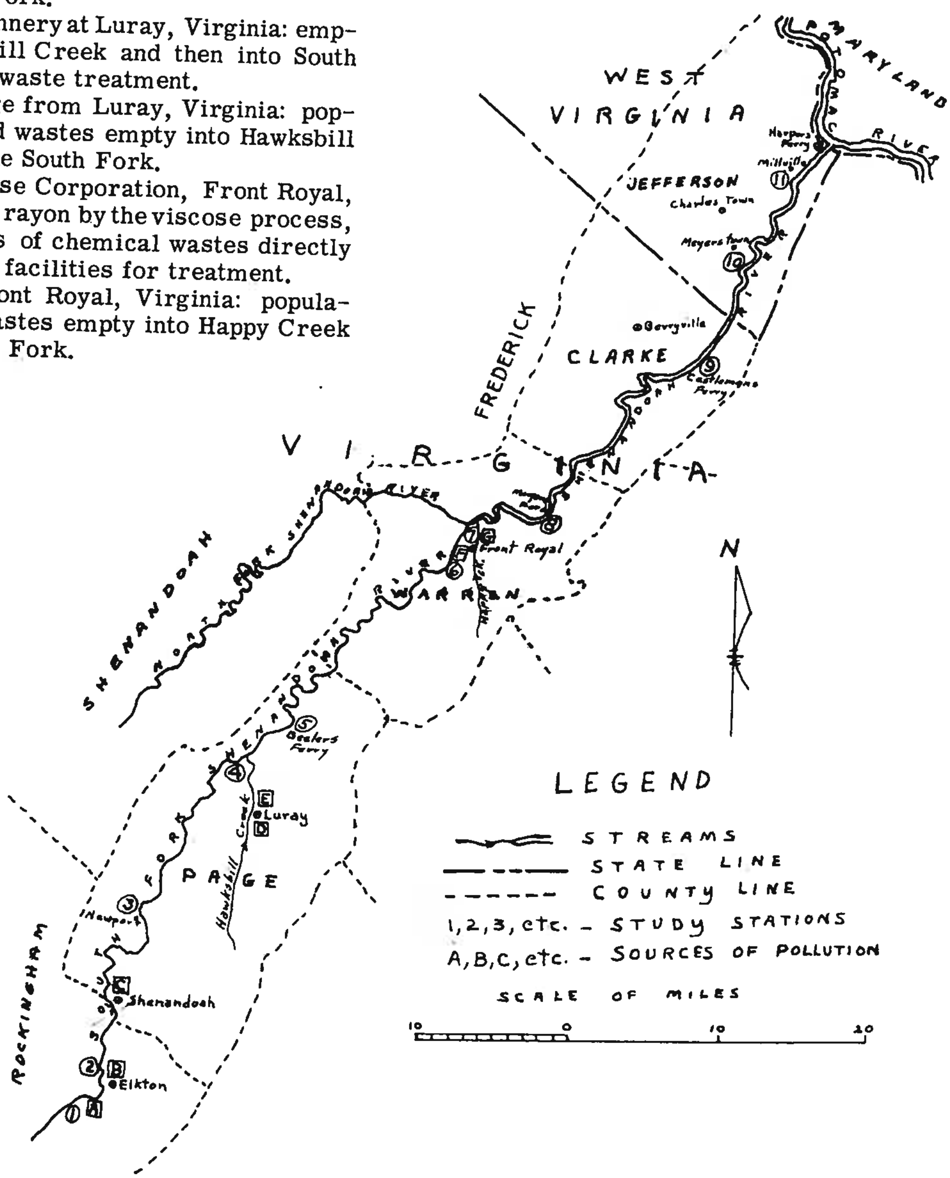
C -- Domestic sewage from the town of Shenandoah, Virginia: population, 1,000; untreated wastes empty directly into the South Fork.

D -- Virginia Oak Tannery at Luray, Virginia: empties wastes into Hawksbill Creek and then into South Fork; has facilities for waste treatment.

E -- Domestic sewage from Luray, Virginia: population, 1,100; untreated wastes empty into Hawksbill Creek and thence into the South Fork.

F -- American Viscose Corporation, Front Royal, Virginia: manufactures rayon by the viscose process, empties large quantities of chemical wastes directly into the South Fork, has facilities for treatment.

G -- Sewage from Front Royal, Virginia: population, 5,200; untreated wastes empty into Happy Creek and thence into the South Fork.



making rayon by the Viscose process (Roetman 1944) and a review of the literature concerning toxicity of various substances to aquatic animals (Ellis 1937), several substances -- among them, xanthates, hydrogen sulphide, and zinc -- were immediately suspected. Xanthates were largely eliminated because of assurance by Viscose Corporation officials that this material could not possibly reach the river and because xanthates could not exist in the effluent under acid conditions. (The effluent was highly acid (pH 2.4) at least at times during the period of major destruction of aquatic animals in the river.) Hydrogen sulphide, though present in toxic quantities in the effluent, was probably eliminated as a result of aeration in the riffle areas of this fast-flowing river. Analysis of the viscose effluent showed zinc to be present in quantities above 2,000 parts per million. In England several workers with lead and zinc mine pollution had shown zinc in quantities as low as 0.2 parts per million to be lethal to some aquatic animals (Newton 1944). Analysis of the water below the Viscose Corporation showed zinc to be present in quantities considerably above this value: tests revealed the presence of zinc at the rate of 0.4 to 11 parts per million, depending on river flow and other conditions. Zinc was thus indicated as at least one of the major factors contributing to the destruction of aquatic life in the river.

Laboratory toxicity experiments were made with both Viscose effluent and pure zinc sulphate to determine the effects on fish and other aquatic animals. It was determined that the Viscose effluent (in concentrations simulating low water and normal river conditions) was deadly to at least some kinds of aquatic animals, and that zinc itself (in quantities present in the river) was toxic to some aquatic animals, such as bass fry, daphnia, and snails. The results of this work with zinc led Viscose officials to set up their own toxicity work with zinc and to put major emphasis on the elimination of zinc from their effluent.

Since the construction of the Viscose Corporation plant in 1940, that organization has expended considerable amounts of effort and money to work out processes for treatment of waste (Roetman 1944). Until 1948, however, the Viscose effluent was treated only a part of the time, and this treatment was entirely inadequate insofar as the aquatic life in the river was concerned. As a result of the publicity received in connection with this study that showed the river to be virtually devoid of aquatic life, the Viscose Corporation has made further effort to improve the treatment of its effluent and has done additional work in reducing the zinc content of that effluent. Reports (April 6, and December 6, 1948) to the Virginia Water Control Board showed much improvement in treating the effluent. At the present writing (June 1949) considerable progress seems to have been made. Complete treatment (ordered by the Virginia Water Control Board to be in effect by March 1949) has been in effect for some time, and the river appears to be recovering.

SAMPLING STATIONS

Eleven study stations (table 1, figure 3) were established at accessible riffle areas above and below possible sources of pollution. Physical, chemical, and biological determinations were made at each station once each month from June to October 1947, and in June and September 1948. These determinations were made at low-water or normal river stages.

PHYSICAL AND CHEMICAL CONDITIONS

Water temperature, hydrogen-ion concentration, dissolved oxygen, free carbon dioxide, and methyl-orange alkalinity (table 2) were determined by standard methods of water analysis (American Public Health Association 1946). Other physical and chemical data were obtained from the West Virginia Water Commission (table 3).

BIOLOGICAL CONDITIONS

In riffle areas near each station, bottom samples were taken with a square-foot bottom sampler used in the manner described by Davis (1938). Square-foot bottom samples were collected, sieved, and preserved in formalin. The animals were later picked out, identified to order, counted, and weighed (wet weight after draining 45 seconds). (See tables 4 and 5.)

ANALYSIS OF DATA

Physical and chemical conditions in the Shenandoah River (tables 2 and 3) are such that by accepted standards (Ellis 1937) the water would be deemed satisfactory to support nearly all forms of aquatic life. In only a very few instances, and then only for short distances below sources of pollution, were dissolved oxygen and pH values such that a good mixed aquatic fauna could not be maintained. Dissolved oxygen values as low as 3.9 parts per million occurred at Station 2 (3 miles below Merck Company) during low water in the summer of 1947 and averaged 5.9 parts per million for the summer, but at Station 3 (less than 20 miles downstream) dissolved oxygen values averaged 8.4 parts per million and at no time were less than 6 parts per million. At no time was a value for dissolved oxygen at Station 1 (above Merck Company) found below 6 parts per million. This tended to show a definite oxygen demand by Merck Company wastes and indicated that conditions below would be somewhat hazardous to certain organisms requiring high oxygen content of water. Bottom-animal samples (table 4, figure 4) appeared to substantiate this belief. Samples at Station 1 contained an average of 912 bottom animals weighing 6.5 grams, while samples at Station 2 averaged only 108 bottom animals weighing 0.42 gram. Samples at Station 3 (25 miles below Merck Company) averaged 528 bottom animals weighing 4.13 grams. A major portion of the bottom animals at Station 2 consisted of oligochaete worms, leeches, and midgefly larvae (animals having low oxygen requirements); while at Stations 1 and 3 there was an abundance of caddis-fly larvae and May-fly nymphs and other types (table 5) which generally require high oxygen content of the water.

Reports from fishermen also tend to substantiate this conclusion. Though carp (fish having low oxygen

TABLE 1.--Station numbers, approximate location, miles between stations, and stream-flow data

Station No.	Location of stations	Miles from Station 1	Stream flow[1/] cubic feet per second 1930-42 average Ave.	Min.	Min. daily
	South Fork, Shenandoah				
1	1 mile above Merck Co., 4 miles south of Elkton, Va.	-	974	32	93
2	3 miles below Merck Co., Elkton, Va.	4	-	-	-
3	25 miles below Merck Co., Newport, Va.	26	-	-	-
4	1 mile above Hawksbill Creek, Shenandoah Lodge, Va.	43	-	70	135
5	5 miles below Hawksbill Creek, Beelers Ferry, Va.	50	-	-	-
6	1 mile above Viscose Co., Front Royal, Va.	86	-	-	-
7	1 mile below Viscose Co., Riverton, Va.	88	1,713	59	103
	Shenandoah River				
8	10 miles below Viscose Co., Morgans Ford	97	-	-	-
9	30 miles below Viscose Co., Castlemans Ferry	119	-	-	-
10	40 miles below Viscose Co., Meyerstown, W. Va.	129	-	-	-
11	50 miles below Viscose Co., Millville, W. Va.	137	2,453	59	194

[1/] Stream-flow data from Geological Survey Water Supply Paper 951.

requirement) were caught quite often in the vicinity of Station 2, few bass were taken. On the other hand, reports showed bass fishing fair to good near Stations 1 and 3.

The low oxygen conditions existing in the summer of 1947 have evidently been corrected. Samples taken in 1948 (table 2) show dissolved oxygen values well above those expected to support a good mixed aquatic fauna. Bottom animals (table 4) have also shown a remarkable recovery in this section of the river and are now present in numbers and weights similar to what would be expected in unpolluted sections of this stream. Certain of the important types such as May-fly nymphs, however, have not yet appeared (table 5). Caddis-fly larvae and hellgrammites have become very abundant.

From Station 3 to Station 6, the river shows little variation in physical and chemical qualities (table 2). All values are well within the limits that may be expected to support a good aquatic fauna. Bottom animals of types expected were abundant in all riffle areas examined in this section of the river (tables 4 and 5). At the beginning of this study, it was expected that wastes from the tannery and sewage from Luray would have some detrimental effect on the river. Field tests, however, did not substantiate this idea. Chemical and biological conditions appeared as good below this possible source of pollution as above. Consequently, Station 4 was eliminated as a study station. Fish kills in Hawksbill Creek were reported to the Virginia Game Commission late in 1947, but no detrimental effects were shown in the Shenandoah, possibly because of dilution.

TABLE 2.--Average, maximum, and minimum values of temperature, dissolved oxygen, pH, free carbon dioxide, and methyl-orange alkalinity, Shenandoah River

Station No.	Water temperature (°F.)			Dissolved oxygen (p.p.m.)			pH			Free carbon dioxide (p.p.m.)			Methyl-orange alkalinity (p.p.m.)
	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
	1938 (May 1 to October 31, 5 samples)[1/]												
9	71			9.0			8.2			0.5			116.5
	1947 (June to October, 5 samples)												
1	69	76	54	7.5	10.3	6.1	7.9	8.0	7.9	2	5	0	
2	71	77	56	5.9	8.7	3.9	7.7	7.9	7.5	3	2	6	
3	72	80	56	8.4	10.6	6.0	7.9	8.0	7.7	0	0	0	
5	74	81	64	9.8	11.3	9.1	8.3	8.6	8.0	0	0	0	
6	76	85	64	10.3	12.8	8.1	8.6	9.2	8.2	0	1	0	
7	79	89	66	7.2	9.4	4.4	5.8	7.4	4.4	65	94	10	
8	78	87	64	8.5	9.4	6.3	7.9	8.2	7.2	0	0	0	
9	78	88	62	8.6	9.6	6.0	8.0	7.7	8.2				
10	-	88	-	8.2	-	-	7.9	-	-				
11	-	88	-	7.7	-	-	8.1	-	-				
	1948 (June 23 and September 29, 2 samples)												
		June	Sept.		Sept.	June		June	Sept.		June	Sept.	
1	68	74	61	8.2	9.1	7.4	8.0	8.1	8.0	0	0	0	145
2	68	74	62	7.0	7.9	6.0	8.0	8.0	7.9	1	2	1	140
3	70	78	62	9.1	9.2	9.0	8.4	8.8	8.0	0	0	0	130
5	71	80	63	9.4	10.0	8.8	8.3	8.5	8.2	0	0	0	131
6	75	82	68	10.2	11.0	9.4	8.5	8.7	8.3	0	0	0	121
7	77	85	69	9.2	10.2	8.2	8.0	8.3	7.7	5	10	0	108
8	75	82	68	9.3	9.9	8.8	8.3	8.7	8.0	0	0	0	126
9	72	79	66	7.9	9.1	6.8	8.2	8.2	8.2	0	0	0	114
10	74	81	64	8.6	9.2	8.1	8.3	8.5	8.1	0	0	0	125
11	76	87	66	8.1	9.0	7.3	8.3	8.5	8.0	0	0	0	123

[1/] Surber, E. W. (1938 data).

TABLE 3.--Shenandoah River stream-survey data furnished by West Virginia Water Commission

	Source of sample								
	Point 1[1]			Point 2[2]			Point 3[3]		
Date of sample (1947)	8/29	9/5	9/12	8/29	9/5	9/12	8/29	9/5	9/12
Laboratory number	44	44	44	43	43	43	42	42	42
Water temperature, °F.	80	79	82	82	78	80	80	80	85
Dissolved oxygen,									
p.p.m.	9.7	7.65	9.75	8.25	7.35	7.7	7.25	6.95	7.9
percent saturation	119	93	122	104	89	95	89	85.5	102
Bio-chemical oxygen demand, p.p.m.	0.5	0.7	0.85	0.5	0.75	1.2	0.5	0.6	1.5
Hydrogen-ion concentration (pH)	8.15	8	8.35	8.28	8.45	8.35	8.2	8.2	8.4
Alkalinity[4]									
methyl orange	100	112	116	117	119	115	121	120	111.5
phenolphthalein	-0.5	-0.5	2	Neut.	5	2.5	Neut.	3	1.5
Chlorides, p.p.m.	10.5	10	14	10	11	12	11.5	10.5	11
Hardness, p.p.m.	141	162	171	149	152	156	160	166	170
M.P. No. Coliform organisms X 1000	<0.11	0.026	<0.11	<1.1	0.026	0.11	<1.1	1.5	0.89

1/ Rt. 7, east of Berryville, Virginia. Corresponds to Station 9.
2/ Rt. 9, east of Charles Town, West Virginia. Corresponds to Station 10.
3/ Millville, West Virginia. Corresponds to Station 11.
4/ Negative alkalinity indicates acidity.

TABLE 4.--Average, maximum, and minimum numbers of bottom animals at each station

Station No.	Number per square foot Ave.	Max.	Min.	Grams per square foot Ave.	Max.	Min.	Pounds per acre Ave.
				1936 (August, 10 samples)			
9	203			10.05			942
				1943 (August, 5 samples)			
6	417			7.45			698
9	4			0.08			7
				1947 (June to October, 5 samples)			
1	912	1,420	340	6.50	10.25	2.18	611
Merck Co.							
2	108	187	78	0.42	1.05	0.18	40
3	528	634	440	4.13	5.01	2.75	390
5	628	866	466	10.55	13.90	4.76	990
6	590	781	325	18.56	23.60	14.45	1,752
Viscose Co.							
7	0	0	0	0	0	0	0
8	70	221	1	0.62	1.50	0.10	59
9	32	92	5	0.12	0.20	0.01	11
10[1]	2			0.05			5
11[2]	19	20	18	0.10	0.10	0.10	10
				1948 (June and September, 2 samples)			
1	1,362	1,469J[3]	1,255S[4]	6.45	7.06J	5.83S	604
2	560	871S	250J	4.07	7.94S	0.20J	381
3	566	675J	458S	1.97	2.39J	1.55S	185
5	714	927S	501J	18.95	20.78J	17.13S	1,776
6	937	1,200S	674J	17.60	27.43S	7.78J	1,649
7	0	0	0	0	0	0	0
8	85	150J	20S	0.29	0.33S	0.25J	27
9	270	367J	172S	0.32	0.42S	0.23J	30
10	187	301J	74S	0.40	0.69J	0.10S	37
11	362	600J	124S	0.64	0.80J	0.48S	60

1/ One sample only.
2/ Two samples only.
3/ J - June.
4/ S - September.

This section from Station 3 to Station 6 (approximately 60 miles) is known far and wide as an excellent smallmouth-bass stream. Many excellent catches of bass, as well as sunfish, channel catfish, and other fishes, are taken during the fishing season.

From Station 7 to its mouth (55 miles), the Shenandoah presents an entirely different picture. Although standard physical, chemical, and bacteriological tests (tables 2 and 3) showed nothing seriously wrong, bottom samples taken in the summer of 1947 (table 4) showed this section of the river to be virtually devoid of aquatic life.

It is possible that, while this section (Station 7 to the mouth) is wholly unfit for fishing, values obtained from standard stream surveys (table 3) would place it in a very high category (Class A, West Virginia Water Commission, 1948). Bottom samples (table 4), however, have shown the marked depletion of aquatic life in this stream. At Stations 8, 9, 10, and 11, values for temperature, dissolved oxygen, pH, turbidity, and carbon dioxide (table 2) have consistently remained within limits that may be expected to support a good aquatic fauna. At Station 7, values for dissolved oxygen and pH were below recognized limits for a short time in the summer of 1947 but have since remained within the desired limits.

Bottom samples (tables 4 and 5) have shown that, though bottom animals of most desirable types were abundant at Station 6 (1 mile above Viscose), in no instances were any bottom animals found at Station 7 (1 mile below Viscose). Samples taken at Stations 8, 9, 10, and 11 showed bottom animals to be extremely limited in both number and desirable type (figure 4).

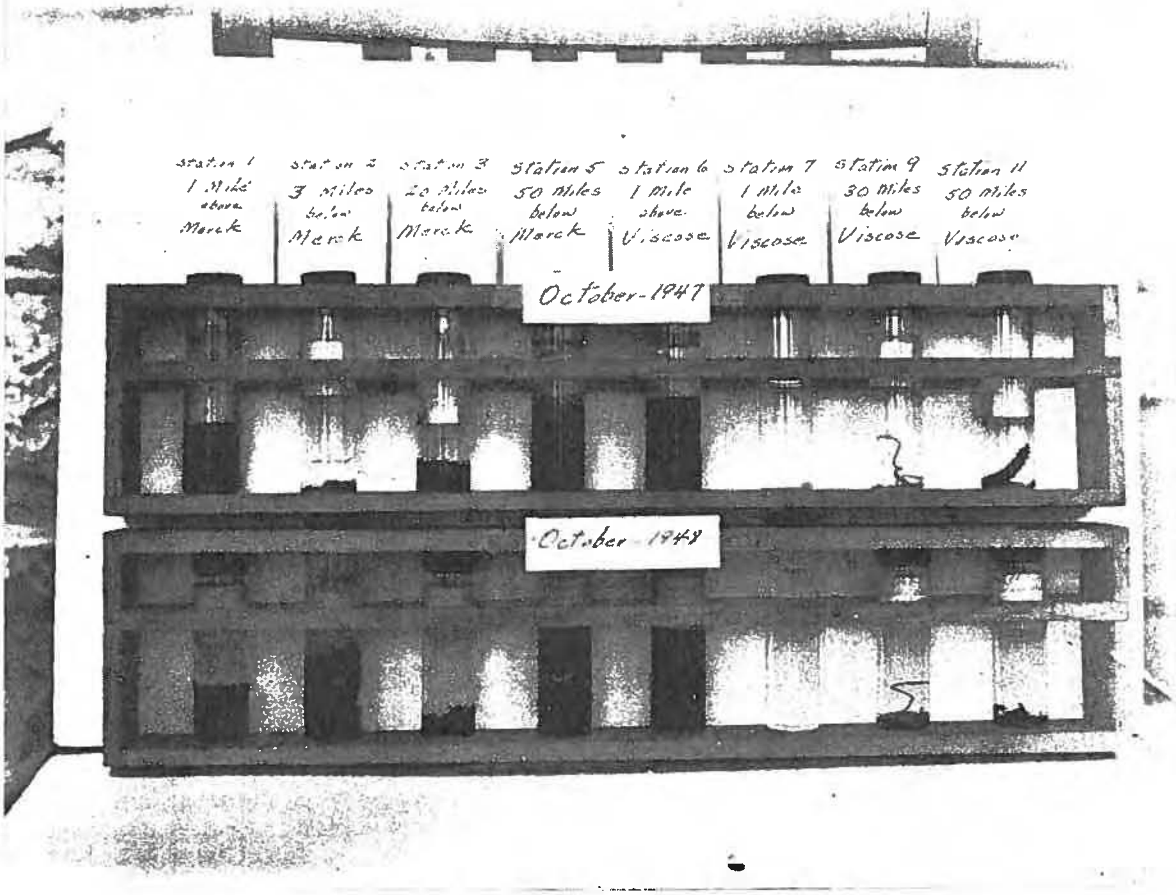


Figure 4 - Bottom animals in square-foot samples.

In August 1943, examining 5 bottom samples taken at Station 6 and 10 samples taken at Station 9 (table 4), Surber found bottom animals at Station 9 reduced 99 percent in average number and 97 percent in weight. The data from Station 9, as compared with data taken at the same station in 1936 (before pollution), showed a reduction of 98 percent in average number and 99 percent in average weight of bottom animals.

Bottom samples taken in the summer of 1947 showed practically the same conditions existing then as in 1943. Samples in 1948 showed a considerable increase in number and a slight increase in weight. This increase, however, consisted almost entirely of midge-fly larvae (Chironomus sp.). Other important fish-food forms, such as hellgrammites, caddis-fly larvae, and May-fly nymphs, have not yet appeared in any degree of abundance.

Though observations in 1947 did not disclose the presence of minnows in the lower river, in 1948 minnows were observed to be present at Stations 8 and 9 and fairly abundant at Stations 10 and 11.

Although fishing in this stream is still extremely limited, reports from fishermen in the summer of 1948 showed that sunfish, channel catfish, and carp were found in the vicinity of Stations 9 and 10. No reports of bass being caught in this section of stream were received, but several small bass (4 to 5 inches) were observed at Station 10.

A fair number of fishermen were observed at Station 11 during the summer of 1948. Though most fishermen considered fishing very poor, quite a few catches of sunfish, channel catfish, and carp--and even a few bass--were reported.

Though some improvement (both chemical and biological) has been made in the lower river, number and types of bottom animals still show a serious state of depletion. No mollusks and very few of the other major fish-food organisms are present (table 5). Until these bottom-animal conditions improve considerably, and until further field studies (including bottom samples) verify such improvement, it cannot be assumed that this section of the river is free of serious pollution.

CONCLUSIONS

1. Pollution surveys ordinarily contain no measure of fish-food organisms or fish in a stream.
2. Standard physical, chemical, and bacteriological methods used in pollution surveys do not necessarily present the true picture with respect to fish and other aquatic animals.
3. The lower Shanandoah River affords an example

TABLE 5.--Average number and kinds of bottom animals per square foot

Station No.	Aquatic earthworms	May-fly nymphs	Midgefly larvae	Caddis-fly larvae	Beetle larvae	Hellgrammites	Snails	Misc.	Total
				1937 (June to September, 141 samples)[1/]					
9	1.7	46.8	16.4	37.4	14.8	3.8	6.8	4.8	132.5
				1947 (June to October, 5 samples)					
1	1	171	176	458	83	1	4	18	912
2	27	0.4	56	7	3	0.2	21	3	108
3	1	44	56	389	5	2	25	5	528
5	0.5	175	89	217	29	2	104	11	628
6	0.2	137	83	156	73	6	129	5	590
7	0	0	0	0	0	0	0	0	0
8	0	3	59	0.8	6	0.4	0	0.6	70
9	0.6	0	30	0	1	0.6	0	0	32
10	0	0	0.5	0	0	0.5	0	0	1
11	0	0	16	0	2	0	0	1	19
				1948 (June to September, 2 samples)					
1	3.5	196	271	766	87	3	11	24	1,362
2	0	2	349	174	10	1.5	23	1	560
3	0.5	22	192	331	1	2	12	5	566
5	5	269	26	162	26	2.5	186	38	714
6	0.5	473	163	158	41	7.5	77	17	937
7	0	0	0	0	0	0	0	0	0
8	1	1	80	1	2	0	0	0	85
9	4	0	262	1	2	0	0	1	270
10	1	0	185	0	1	0	0	0	187
11	0.5	3	348	8	1	1	0	0	362

[1/] Surber, E. W. (1942).

of a large stream that is relatively free of pollution according to accepted physical, chemical, and bacteriological standards, yet contains virtually no fish or other aquatic animals because of toxic elements from industrial wastes.

4. The Surber bottom sampler is a tool which may be used, in the Shenandoah River and in similar streams, to determine the impact of pollution on fish-food organisms and consequently on fish. By the simple method of using this sampler, the source, degree, and extent of pollution may be determined.

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AQUATIC ORGANISMS AS AN AID IN SOLVING WASTE DISPOSAL PROBLEMS*

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This paper discusses the various ways in which aquatic organisms may be of use in solving problems associated with waste disposal. Since many state and federal laws set forth that nothing may be discharged that is deleterious to aquatic life, the most expedient way to determine the effect of an effluent is to study the aquatic organisms themselves.

In every river that has not been adversely affected by pollution there is a great variety of aquatic life. These organisms do not represent a great mass of living things, but rather they are organized into an intricately balanced system, often referred to as a food chain of biodynamic cycles.

Bases of Food Chain

At the base of the food chain are the bacteria. These organisms use the complex wastes entering a river as a source of energy in their metabolism. In so doing they break down the wastes into substances that can be used as a source of food by other organisms. These processes, which are often referred to as decay or decomposition, occur most rapidly when the bacterial population is of optimum size. When the bacteria become too numerous the processes are slowed down. The protozoa and other small invertebrates which feed on bacteria are instrumental in keeping the bacterial populations in check.

The algae are also at the base of the food chain. They are able to utilize inorganic substances to make proteins and carbohydrates, which are used as a source of food by other organisms. Indeed algae have often been referred to as the grasses of the sea. Upon them not only the many different invertebrates, but also some fish and other vertebrates, feed directly. Besides their value as a source of food they also replenish the oxygen supply of a river by a process known as photosynthesis. This is the method by which carbohydrates are synthesized and oxygen is given off as a by-product. Indeed, in many rivers this is the principal way in which oxygen is restored after it has been depleted.

The algae and the bacteria are the most important organisms in bringing about the "rejuvenation" or "cleansing" of a river. The roll of the fungi is also significant in this respect, but as yet not as well understood.

Many Food Chains Involved

As previously stated, many invertebrates, such as the worms, the snails, and the insects, feed directly on the bacteria, the fungi, and the algae. They in turn are a source of food for the carnivorous species; thus, a closely integrated food chain is formed.

This food chain does not consist, however, of a single series of links, but rather of a series of chains that are sometimes interlinked. Thus, pollution may break one series of links, yet not completely destroy the chain. It is only when pollution is extreme that the chain is completely broken and the higher forms of life are completely eliminated. Thus, when one is concerned with the problems of waste disposal and river conservation, he must concern himself with the whole pattern of life in the river rather than just one group; for example, the fish.

Pollution Effects

There are commonly five ways in which wastes may harm the aquatic life of a river, as follows:

1. They may produce oxygen deficiency. This may be due to the bacteria, which attack the wastes and use oxygen in their metabolic processes. The wastes also may not be completely oxidized when they are discharged and thus take up oxygen from the water in completing the oxidation necessary to stabilize them.
2. They may be toxic to aquatic life. This may be due to the nature of the chemicals themselves. However, it may be due to the pH which they create in the river. Wastes also may be toxic due to the osmotic pressure which they develop in river water, thus bringing about conditions unfavorable for aquatic life.
3. Temperature changes produced by wastes may be harmful in two ways. The amount of change which they produce may be deleterious. It is a well known fact that a sudden change in temperature of more than two degrees is harmful to the sunfish. Also, a waste, by raising or lowering the temperature of a river only two degrees, may cause the temperature of the water to be in a critical range deleterious to the functioning of certain physiological processes necessary for life.
4. The physical properties of the wastes may be harmful. They may carry suspended solids that are abrasive and thus injure mechanically the membrane of the gills of fish. In other cases, such as oil, they may coat the gill structures and thus make the absorption of oxygen from the water impossible.
5. Wastes may render the habitats of aquatic organisms untenable. For instance, suspended solids may settle out and clog up the natural habitats of aquatic organisms. Eggs may become buried. In other

*Presented at 25th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; NewYork, N.Y.; Oct. 6-9, 1952 cases the added pressure created by settleable solids may cause the egg cases to burst. Some wastes produce turbidity, thus hindering light penetration. Thus, the photosynthetic zone of a river will be greatly restricted and the algal production limited.

Besides bringing about death of organisms, waste may lower their resistance to the normal factors in the environment so that eventually the population dies out. To date these effects of wastes have been studied very little.

The Academy of Natural Sciences of Philadelphia has used two approaches to study the effect of pollution on a river - laboratory tests and river surveys.

Laboratory Tests

For determining the oxygen consumption of a waste, a combination of tests are used: immediate oxygen demand, biochemical oxygen demand, and complete oxygen demand. These tests are well described in the literature.

The methods for determining the toxic effects of wastes on aquatic life have, to a great extent, been developed in the Academy laboratory. A considerable part of this work was done with the aid of a grant from the American Petroleum Institute.

Realizing the importance of the bio-dynamic cycle, the effect of a given waste is determined by using organisms representing three stages in the cycle. These organisms are as follows:

1. An alga that is important as a producer of oxygen, and as an organism that can convert inorganic substances into a direct source of food for many aquatic animals.
2. An invertebrate that serves as a direct food for fish. As representatives of this group, insects and snails have been used.
3. Fish, because of their recreational and economic importance.

The fish tests are conducted according to the methodology set forth by the Federation's Subcommittee on Toxicity (1).

Insect and Snail Tests

The insect and snail tests have been patterned after the fish tests. As with the fish, care is taken to assure that the organisms are thoroughly acclimated to laboratory conditions. This is determined by a very low death rate and by the fact that growth is taking place in the acclimatization tank over a period of time. This takes several weeks, and sometimes months, to ascertain. The invertebrate tests are conducted under constant temperature and dissolved oxygen conditions. A constant volume of fluid to organism is maintained. The organisms are not fed during the test. As in fish, death is a difficult condition to establish. It is defined as lack of response to tactile stimulus and failure to recover. This is accompanied by various changes in the appearance of the organisms. In insects the same procedures as those used with fish are followed. In the case of snails, after they fail to respond to tactile stimuli, they are placed in uncontaminated water in which they have been reared. If they do not recover in 48 hr., they are determined to be dead.

Algae Tests

The algae test, although similar fundamentally, are quite different from the fish or insect tests. For these tests the diatom Nitzschia linearis was chosen. This diatom is commonly found in eutrophic streams and rivers which have not been adversely affected by pollution in the eastern and midwestern sections of the United States. The tests are conducted in Erlenmeyer flasks. The light source is artificial, being a combination of neon and "daylight" fluorescent lights. The tests are usually conducted at 18° to 20° C., depending on the temperature of the water into which the waste being tested will be discharged. The dilution water, as in the case of the fish, is a natural water or a synthetic water, which has been selected because it matches in chemical composition the water of the river into which the waste will be discharged.

The diatom cultures used in these tests consist of a single species of algae. They are cultured in the laboratory several months before testing, and are known to be maintaining a division rate characteristic of healthy diatoms of this species. Since death is a difficult thing to determine in a diatom, the point at which the growth rate is decreased 50 per cent below that of the control is taken as comparable with the median tolerance limit obtained in fish tests.

In the course of experimentation it has been found that the rate of growth is influenced by the size of the inoculum. Therefore, it is necessary that the same size inoculum be used in the control as in the tests. This is verified by counting the number of cells per milliliter in each flask at the beginning of the experiment. All tests, as well as the control, are run in duplicate. All subsequent counts are made in the same manner as at the beginning of the test to determine the rate of growth.

The duration of the test should be from 5 to 7 days. Often, at the beginning of an experiment, there is a "lag" effect before the diatoms respond to the test medium. This effect may last for 48 hr. From the third to the seventh day is the time when the growth rate can be most accurately correlated with the effects of the test medium. After this length of time some of the necessary nutrients in the dilution water may be used up and the effect produced may be due to malnutrition rather than to toxicity.

The tests described are acute toxicity tests. It is hoped that chronic toxicity tests may be developed in the near future. This would help to determine whether a substance would lower the resistance of an organism so that it could not successfully compete in nature.

Value of Laboratory Toxicity Tests

The tests described would be of value to industry in solving the following types of problems.

1. In the planning of waste disposal, (a) to determine just how much of each type of waste can be safely discharged into a river and (b) to separate the unharmful from the toxic wastes and thus reduce the cost of waste treatment.
2. In changing a process, to determine whether a new process will produce a more severe waste problem.
3. In installing new types of waste treatment, to determine whether the effluent from such a treatment is as harmless as the specifications state.
4. When dumping settling basins at high river flow, to determine how much can be dumped at a given flow without damaging the aquatic life.
5. When an industry is accused of causing a given damage and there are many other effluents emptying into the river, to determine whether or not the accused industry is to blame.

River Surveys

The second approach to solving waste effluent problems is the biological survey of the river. As every aquatic biologist knows, the ecology of the river is a very complex result of many interacting factors. Because of this, no series of toxicity tests can accurately determine the effect of a waste in a river. They merely provide an approximation of what will happen. The only way to know the effect of a waste on a river is to study the river itself.

The methodology for conducting a biological survey was published in the Proceedings of the Academy of Natural Sciences of Philadelphia in 1949. In a river survey, all of the organisms established in a given region of the river are identified as to species. The chemical characteristics of the water are determined. A total bacterial count and a coliform count are made, and the B.O.D.'s are determined.

A histogram is made of each region studied. The heights of the columns are determined by the number of species of each group of organisms living in that part of the river. Since the various groups vary greatly as to the number of species in them, the height of a given column is expressed as a percentage of the number of species of that group found in a river not adversely affected by pollution. By this method the various columns are comparable.

From the pattern developed by the columns of a histogram, the state of "health" of a river is determined. Research makes it evident that the pattern of life based on all groups of organisms is a more reliable criterion for judging the "health" of a river than a single group of "indicator organisms." Just as in other scientific work, the more different evidence available to support conclusions, the more valid they usually are.

Value of River Surveys

One of the great values of this type of study is that it tells the condition in the river over a period of time. Because these aquatic organisms have life histories of varying lengths, one is able by examining the structure of the population to determine when in the past a deleterious effect occurred. This effect can be picked up over a period of a year and sometimes longer. It depends, of course, on the kind and duration of the pollution.

This type of river study may be of use to the industrialist in the following ways:

1. Such a survey before an industry starts to operate will define the condition of the river at that time. There are few large rivers in the eastern part of the United States which have not to some degree been adversely affected by pollution. It is well for the state authorities, as well as the industry, to know what the condition of the river is before the industry starts to operate.
2. This method is useful in determining whether a waste treatment program is sufficient to protect the river, or if more treatment is needed.
3. If an industry is accused of damaging a river, such a survey, comparing various sections of a river, can tell if the complaint is justified.

Such a survey is certainly the most direct approach to use in determining the condition of the river. It is believed that by the previously described toxicity tests and biological surveys definite methods have been developed which should be of great aid to industries and to states in defining their pollution problems.

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DISCUSSION

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Cleaning up the rivers, lakes, and bays of the country will require a great deal of money and the cooperative effort of many different groups of people. To accomplish this task and properly control the disposal of industrial and municipal wastes into surface waters, the pollutional nature of these wastes and their influence on aquatic life must be considered.

The value of fishery resources and the magnitude of the economic loss caused by the destruction of aquatic life by the industrial and municipal pollution of waters are being more widely recognized. Many states have adopted legal measures providing for the protection of fish and other aquatic life from pollution. While some have interpreted this legislation as applying only to the acute poisoning or killing of fish, Dr. Patrick's group has dealt with the fish food organisms, as well as the fish, and also has given consideration to the chronic effects of wastes on aquatic life.

In studying the effect of pollution on a river, the best type of biological program is that which recognizes the complexity of the ecological factors involved. In combining laboratory tests with river surveys, the author is attempting to gather as many different types of evidence as possible before drawing any conclusions. She is to be commended for using an approach which is more thorough than that normally used in the past for examination of this complex problem.

The need for experimental studies dealing with the toxicity of pollutants to aquatic life is great. Dr. Patrick has already discussed some of the methods and the importance of conducting such toxicity tests. Fish bio-assay procedures for most industrial wastes are not costly and are not especially difficult to perform. On the basis of toxicity determinations, it is usually possible to predict whether a waste can be discharged at a given rate without causing direct injury to fish in the receiving water. Such data also are helpful in determining the amount of treatment required, the portion of the waste requiring treatment and the effectiveness of treatment methods (1).

It has been mentioned by Dr. Patrick that another use of this method is to determine whether the discharges of a given industry are responsible for causing damage when there are many effluents emptying into the river. In such a case the character of the receiving stream is of considerable importance in determining the toxicity of a waste. Further, the toxicity of wastes can be greatly influenced by interactions between their individual components and the dissolved minerals present in widely varying amounts in receiving waters. For instance, the salts of heavy metals are generally more toxic in soft or acid waters than they are in alkaline water. Synergy and antagonism must be considered. For example, mixed solutions of cupric and zinc salts have been found to be much more toxic to minnows, than either metallic salt alone (2).

Dr. Patrick's method for conducting a biological survey of a river is to be commended for the completeness of its scope and for attempting to formulate criteria which might be useful in evaluating the effects of pollution on streams. However, for many purposes it should not be necessary to conduct such extensive or complicated studies as those outlined.

The concept of a healthy stream as being one with a large number and wide variety of species may serve as an index of conditions in some streams, but there are many areas in which it will not apply. For example, in many of the purest streams the variety and abundance of both fish and invertebrate life is distinctly limited. In Colorado and Utah many trout streams have a fish fauna of as few as 3 to 5 species and the variety and abundance of bottom fauna depends largely on the geological nature of the drainage basin (3) (4). The water in these streams is clear, sparkling, and usually meets drinking-water standards. These streams are not biologically abnormal or polluted from any standpoint.

Although heavy pollution drastically reduces the number and variety of species in a stream, limited organic pollution may fertilize a stream and increase production. There is also a great increase in the varieties of aquatic life following recovery in streams polluted with many organic wastes. Many polluted streams have a greater number of fish species than do the purest streams. Indices of stream conditions developed in a local area should be applied only in those areas having similar ecological characteristics.

In stream sanitation work it is not essential that the biodynamic cycle be preserved in its primitive condition. Such conditions have already been largely eliminated by deforestation, overgrazing, mining, and agricultural practices. The objective now is to manage waters so that they will produce the maximum sustained yield of recreation and sport and commercial fishing consistent with the capacity and other reasonable uses of the waters. Among the aquatic fresh-water organisms, fish are the most important to the general public. The destruction of a few sensitive species is of little importance if they are replaced by others equally desirable so that the fish yield is not impaired. In the final analysis the fish yield is the important measure of effective stream management and fishlife should be considered as the major index of stream conditions.

Dr. Patrick's system for making stream surveys is costly and requires the help of a considerable number of well-trained scientists for it to be usuable. Many state agencies charged with water pollution control, as well as small industries, do not have money or personnel for a biological program of the magnitude recommended.

When conducting biological investigations for the evaluation or solution of pollution problems, careful formulation of objectives is required. If the objective is to determine only general stream conditions, a reconnaissance survey is favored to determine the relative quantitative and qualitative aspects of the biota. In such a program the pollutional condition of a stream can often be determined by reference to those groups of organisms which best reflect the ecological conditions under which they live. If the objective of a stream survey is to ascertain the economic loss caused by the damaging effects of pollutants on the fishery of the stream, then it is necessary to determine the composition of the fish fauna in the stream and the changes in that fauna which might have occurred in the past. Necessary data on fish populations and yield can be obtained by creel censuses, records of commercial catches, seining, gill netting, trapping, etc. Since the procedures for conducting fishery yield surveys have been fairly well standardized by workers in fish management, it is not deemed advisable to dwell further on the subject here.

Several different approaches have been advocated by biologists in using aquatic organisms as indicators of the pollutional conditions of a stream. Dr. Patrick, emphasizing primarily a qualitative approach, maintains that the total number of species, rather than the qualitative and quantitative characteristics of the population, constitutes the most valuable index as to the health of a stream. Ellis (5) advocated a semi-quantitative approach when he stated that the relative abundance of indicator species was the important consideration. Biologists of the USPHS Environmental Health Center at Cincinnati, Ohio, have found that both criteria are important and serve best when used concurrently. For example, Gaufin and Tarzwell (6) found that in a small polluted stream near Cincinnati, the biota in the polluted zones was characterized by few species but large numbers of individuals, whereas in the clean-water zones there were many species but comparatively few individuals of each species.

Quantitative measurements of the total number of species or individual organisms in any given area of a stream are often difficult to obtain. For example, Environmental Health Center biologists took a series of nine random samples, by means of an Ekman dredge, from a pool in a small sewage polluted stream near Cincinnati. A total of 50 species of macro-invertebrates was collected. On the average, it was determined that any three of these samples would have yielded only 60 per cent of the 50 species. Seven samples would have been required to have obtained 90 per cent of the types represented.

Where personnel are not available to do all of the technical taxonomic work required for species identification, or to take enough quantitative samples to accurately determine the abundance of individual species or organisms, a practical biological inventory is still possible.

Specifically, the degree and extent of pollution in a stream can be determined accurately by reference to the macro-invertebrate fauna, particularly that found in the riffles. A biological analysis of the pollutional status of a stream can be obtained in the field through recognition of the biological orders, families, or genera in the invertebrate associations encountered. This type of biological inventory is superior to limited chemical data, as the complex of such organisms which develops in a given area is in turn indicative of present, as well as past, environmental conditions in that area. Bottom organisms are more fixed in their habitat than are fish or plankton and cannot move to more favorable surroundings when pollutional conditions are most critical.

Shortened procedures, such as that suggested, cannot be recommended for use by anyone except a well-trained aquatic biologist. When used properly, however, such techniques can be of considerable value to organizations having waste disposal problems to solve.

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DISCUSSION

By Ruth Patrick

As Dr. Gaufin has pointed out, there may be a synergistic effect between an effluent entering a river and substances already in a river. For this reason toxicity tests may be used as a yardstick, but one must study the river itself to determine accurately the effect of an effluent.

It is true that there are many different types of rivers in the country, with varying amounts of aquatic life. However, the writer has yet to find a river with two ecologically similar areas; one adversely affected by pollution with industrial or municipal wastes, and one unpolluted in which the unpolluted area did not have a greater diversity of species of diatoms, insects, and fish than the polluted area.

It is correct that a well-qualified biologist can determine that a river is badly polluted without determining all the species. But if it is desired to determine trends of conditions or have definite evidence for future comparison, the species present must be determined.

Very rarely are all the species of a genus indicators of pollution. For this reason, it would be very dangerous to draw positive conclusions from determination only to genus.

Dr. Gaufin indicated that the method described is a qualitative one. It is qualitative in that the kinds of species composing the biodynamic cycle are considered. It is, however, quantitative in that the measure also considers the number of species. No one has yet devised a statistically valid quantitative method for benthic forms in a river based upon the number of individuals.

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EFFECTS OF SILTATION, RESULTING FROM IMPROPER LOGGING, ON THE BOTTOM FAUNA OF A SMALL TROUT STREAM IN THE SOUTHERN APPALACHIANS

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SILTATION, RESULTING FROM IMPROPER LAND - USE PRACTICES, is regarded as one of the most important factors contributing to a reduction in the acreage of desirable fishing waters in the United States. Although much information of a general nature has been published, there is a lack of quantitative data regarding the effects of siltation on stream values.

One phase of a Dingell-Johnson project, established by the North Caroline Wildlife Resources Commission during the summer of 1952, was to obtain quantitative data regarding the effect of siltation on trout streams in the southern Appalachians. The project was begun on the Coweeta Experimental Forest, located in Macon County, North Carolina, where for 20 years the U. S. Forest Service has been collecting extensive data regarding the effects of various land-use practices on experimental watersheds. The purpose of this report is to present data regarding the effects of siltation on the bottom organisms of Shope Creek, a small trout stream which received the drainage from a 212-acre logged watershed (figure 1).

During 1942, logging was commenced on the 212-acre watershed on the Coweeta Experimental Forest. The periods of activity on the watershed were:

May 1942 - Mar. 1943: Active logging
Mar. 1943 - Jan. 1945: No logging
Jan. 1945 - Nov. 1948: Active logging
Nov. 1948 - Apr. 1953: No logging
Apr. 1953 - Present: Active logging

The logging was carried out by local contractors, with no limitation of methods or supervision by the Forest Service. Logs were ground-skidded by teams. Because of steep slopes, the roads and skid trails were built parallel and adjacent to the channel of the drainage stream. The roads were characterized by excessively steep grades alternating with level stretches. No surfacing material and no drains or water cutoffs were used on the roads. With the termination of the original logging in 1948, 2.2 miles of road had been constructed on the 212-acre watershed.

Presented at the Eighth Annual Conference of the Southeastern Association of Game and Fish Commissioners, New Orleans, Louisiana, November 1-3, 1954, to report on one phase of a Dingell-Johnson project undertaken by the U.S. Fish and Wildlife Service, U.S. Forest Service, and North Carolina Wildlife Resources Commission.

Description of Shope Creek

Shope Creek, which received the stream from the logged watershed, flows into Coweeta Creek and thence to the Little Tennessee River. Shope Creek drains a watershed of approximately 1,880 acres and is typical of many smaller trout streams in the southern Appalachians. Average monthly streamflow for a 6-year period ranged from a low of 2.31 c.f.s. during October to 8.32 c.f.s. during February (figure 2). Figure 3 illustrates the frequent occurrence and magnitude of floods occurring in this small trout stream.

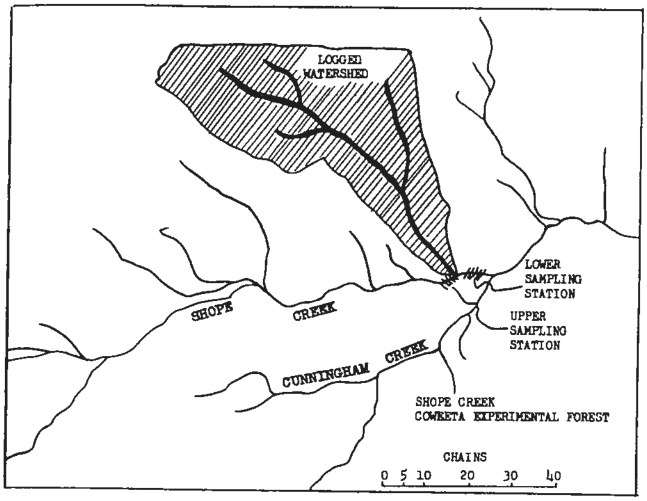
During the period of this study, stream temperatures have ranged from a low of 33.0°F. during December 1952 to a high of 65.5°F. during August 1953. During the fall of 1953, the water had a pH of 6.6 and a methyl orange alkalinity of 8.0 p.p.m.

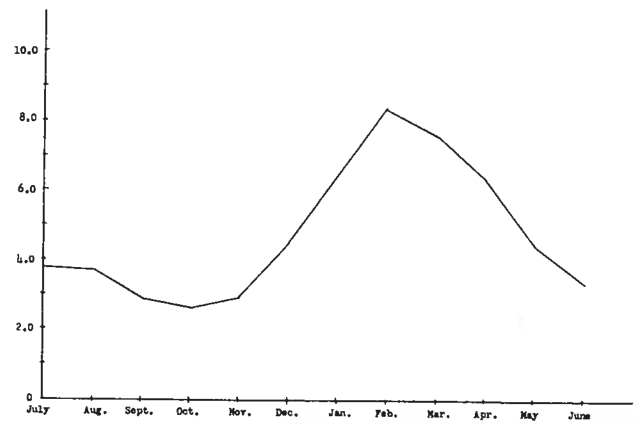
The upper portion of the stream is characterized by steep gradient (900 feet to the mile) with series of cascades and low waterfalls, interspersed with large pools having excellent shelter in the form of large boulders and broken water surface. The bottom is predominantly boulders and rubble with occasional outcrops of granite bedrock. From approximately one-fourth mile above the sampling stations to the lower boundary of the experimental forest, there is a noticeable change in the habitat. The gradient is 224 feet per mile, and the cascades and waterfalls of the upper section are replaced with short riffles and shallow pools. There is no rooted aquatic vegetation in the stream.

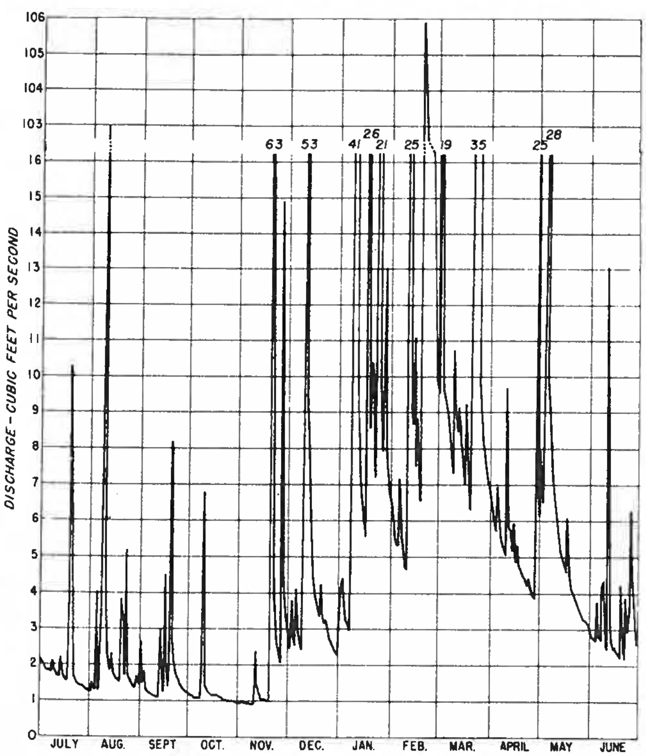
As nearly as can be determined, no trout have been stocked in Shope Creek since 1930, when rainbow trout were introduced by local residents. At present, the upper and lower reaches of the stream contain brook and rainbow trout, respectively, with an intermingling of these two species in the section just above the mouth of the stream from the logged watershed. No fishing has been permitted for the past 4 or 5 years. However, prior to closure, the stream had an excellent reputation among local fishermen.

Water Quality

During storm periods, the effect of the stream from the logged watershed (Watershed No. 10) on Shope Creek is illustrated by the turbidity of water samples collected at the mouth of the stream from No. 10, from Shope Creek above the mouth of No. 10, and from Shope Creek below the mouth of No. 10.







Date	Turbidity (p.p.m.) Stream from Number 10	Shope Creek Above 10	Shope Creek Below 10
Apr. 11, 1947 ---	1,200	25	390
Feb. 20, 1954 ---	1,371	67	261

The roads and skid trails proved to be the major source of turbidity (Lieberman and Hoover 1948). Skidding logs down the steep slopes creates channels which concentrate runoff, resulting in a high rate of erosion. For the 2-year period from April 1951 to March 1953, an average of 5.34 cubic feet of soil per lineal foot of road surface were eroded from the logging road. This would amount to a loss of 2,297 cubic yards of soil for the total 2.2 miles of road system.

During periods of low streamflow, the physical effects of siltation on Shope Creek are noticeably evident. During the low flows of late summer and fall, the bottom of Shope Creek above the mouth of the logged watershed accumulates a thin layer of finely divided organic matter, while below the mouth of the logged watershed the stream bottom in both pools and riffles is covered with a layer of sterile sand and micaceous material which may accumulate to a measured depth of 10 inches.

Bottom Fauna

Because of its relative stability in location, the bottom fauna was selected to obtain a measure of the effects of siltation on the stream community. The limited section of Shope Creek affected by siltation from the logged watershed made a direct evaluation of the fish population impractical. The small stream from the logged watershed is too small to support a resident trout population.

Within limits of space and reproductive capacity, the available food in a stream can certainly be regarded as a factor limiting the production of trout. Leonard (1948) and Henry (1949) have stated that in Michigan trout waters the food supply often is the most important limiting factor in trout production. Allen (1951), working on New Zealand streams, found that the bottom fauna was a limiting factor in the production of brown trout. Tarzwell (1938b) found an apparent relation between the quantities of stream foods present and trout production in streams in the southwestern United States.

(Top to Bottom)

FIGURE 1. -- Map of Shope Creek, Coweeta Experimental Forest, showing the location of logged area and sampling stations.

FIGURE 2. -- Mean monthly streamflow (c.f.s.) of Shope Creek for the 6-year period, 1937-42.

FIGURE 3. -- Peak daily streamflow (c.f.s.) of Shope Creek for the period, July 1952 to June 1953.

(Drawings courtesy of the author)

In trout streams of western North Carolina the food of trout is obtained from three sources: the bottom fauna, terrestrial insects, and fish. Analysis of 241 rainbow trout stomachs collected from streams of western North Carolina during 1952 and 1953 indicate that, from January to June, 83 percent of the diet is obtained from the bottom fauna. From June to December, 42 percent of the food of rainbow trout is obtained from the bottom fauna. Terrestrial insects are of major importance during the summer and fall months. Of the 241 trout stomachs examined, only 1 specimen contained fish remains and 3 had eaten salamanders.

From October 1952 to June 1953, 108 square-foot bottom samples were collected at monthly intervals from Shope Creek immediately above and below the mouth of the stream draining the logged watershed. The standing crop of bottom organisms was at all times very low, with a high average of 49.0 organisms per square foot occurring at the untreated station on November 13 (table 1). The highest average volume occurred in the samples of January 14 at the untreated station. The high volume occurring on January 14 resulted from an abundance of large cranefly larvae, *Tipula* sp., and the stonefly nymph, *Pteronarcys scotti.* The frequent occurrence of floods (figure 3) is undoubtedly an important factor contributing to the low quantities of bottom fauna produced in this small trout stream.

From October 1952 to February 1953, the upper station had a significantly larger numerical standing crop of bottom organisms than did the lower station, which was subjected to the siltation from the logged watershed (tables 2 and 3). The volume of bottom organisms was greater in the control section on all but two sampling dates, April 23 and May 21, 1953 (table 1).

A major flood that occurred on February 21, 1953, increased the flow in Shope Creek from 6.7 c.f.s. to 105.8 c.f.s. in a 24-hour period (figure 3). The flood completely resorted bottom materials and flushed the deposited sediments downstream, exposing the original rubble and gravel bottom. On February 26, 1953, the numbers of bottom organisms at the lower station had been reduced 73.2 percent, as compared with the January level, while the numbers at the untreated station had been reduced 22.2 percent (table 1).

High water levels plus frequent rains February to May (figure 3) prevented a reaccumulation of silt in the lower section of Shope Creek. On April 2, April 23, and May 21, that section of stream produced slightly greater standing crops of bottom organisms than did the control section. The difference was not significant ($F = 0.208$ d.f. $= 1$ and 30), and was the result of an increase in the numbers of mayfly nymphs in the treated section of stream (table 1). The inexplicable superiority of mayflies in the treated section of stream may have been the result of reduced competition and improvement in habitat, both caused by the February flood.

When samples were collected in June 1953, silt and sand again had begun to accumulate in the treated section of the stream, and the control section again produced a greater average standing crop of bottom organisms (table 1). The difference was not statistically significant ($t = 1.42$ d.f. $= 10$).

Before the reduction in the quantity of stream bottom organisms, from October through February, can be attributed to the effects of siltation, it is necessary to assume that there was no difference between the two sampled stations prior to logging. The study was commenced quite some time after logging took place, and it is therefore impossible to test this basic assumption. However, the fact that the sampled areas are on immediately adjacent and similar sections of the same stream, as well as the comparable quantities of bottom fauna produced during the spring months, when silt did not accumulate in the treated section of the stream, lends support to the assumption that there were no pretreatment differences between the two stations sampled.

With the exception of the difference in mayflies during the spring months, as noted above, there were no appreciable qualitative differences between the two stations sampled (table 1).

Discussion

The period during which the standing crop of organisms in the treated section of Shope Creek was significantly lower than in the control section coincided with the period of maximum accumulation of inorganic silt and sand. Inorganic silt and sand have poor ability to support a fauna. Tarzwell (1938a) found that mineral silt bottoms were poor in food. Murray (1938) stated that, in Indiana streams, sand by itself is likely to be barren of life.

In addition to its poor ability to support a fauna, the shifting sand created an unstable habitat, and organisms inhabiting it were particularly vulnerable to decimation by flood waters. The flood during February removed the accumulated sediments and resulted in a drastic reduction in the number and volume of bottom organisms in the treated section of stream. During the high flows and frequent rains from February to May, the rate of dilution by clear water from the main fork of Shope Creek prevented the reaccumulation of sediment in the treated section of stream. A fauna which resulted was quantitatively comparable to that found in the control section. It is doubtful that the rapid recovery after the flood -- undoubtedly by means of the drift of organisms from the control section -- could occur if all of the Shope Creek watershed were subject to the effects of siltation.

The low fertility and frequent occurrence of floods in western North Carolina trout streams results in a low production of stream bottom organisms under the very best conditions. Therefore, because of the dependence of trout on stream-produced organisms, any outside factor, such as siltation, which reduces the normally low quantities of stream organisms will ultimately have a deleterious effect on the trout population.

It is apparent from the Coweeta studies that poorly planned road systems and the promiscuous use of smaller stream channels as skid trails result in a

TABLE 1.--Numbers and volume of bottom organisms collected from riffles in Shope Creek from October 1952 to June 1953 at stations above and below the mouth of a tributary stream draining a logged watershed

	October 16		November 13		December 17		January 14		February 26	
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Number of samples	3	3	3	3	6	6	6	6	6	6
Total number of organisms	116	74	147	78	226	137	234	164	182	44
Number per square foot	38.7	24.7	49.0	26.0	37.5	22.8	39.0	27.3	30.3	7.3
Standard deviation	9.29	13.0	12.1	14.7	13.6	6.80	15.4	16.9	22.3	3.19
Total volume (cc)[1]	0.70	0.15	0.70	0.20	3.20	0.50	5.70	2.40	2.65	trace
Volume per square foot	0.23	0.05	0.23	0.07	0.53	0.08	0.95	0.40	0.44	trace
Diptera	27	4	57	33	65	55	90	70	76	13
Trichoptera	18	12	7	5	25	20	19	9	10	4
Plecoptera	25	9	49	-----	57	24	50	18	9	6
Ephemeroptera	30	23	22	29	53	23	54	51	36	16
Odonata	1	-----	------	-----	2	------	2	1	1	-----
Coleoptera	11	25	12	11	23	15	19	15	21	5
Oligochaeta	4	1	------	-----	------	------	------	------	------	-----

	April 2		April 23		May 21		June 12	
	Above	Below	Above	Below	Above	Below	Above	Below
Number of samples	6	6	6	6	6	6	6	6
Total number of organisms	259	283	239	249	180	196	256	202
Number per square foot	43.2	47.2	39.8	41.5	30.0	32.7	42.7	33.7
Standard deviation	17.6	17.6	19.3	26.6	9.27	15.2	11.3	10.7
Total volume (cc)[1]	5.20	3.75	2.50	2.70	1.35	2.60	3.80	1.20
Volume per square foot	0.87	0.63	0.42	0.45	0.23	0.43	0.63	0.20
Diptera	41	33	32	24	25	16	9	10
Trichoptera	13	11	8	5	4	11	18	16
Plecoptera	41	29	24	20	17	31	75	21
Ephemeroptera	148	190	160	189	106	130	112	127
Odonata	------	1	------	------	------	------	2	------
Coleoptera	15	17	12	10	25	5	29	24
Oligochaeta	------	------	1	1	2	2	4	1
Crayfish	1	1	1	------	1	1	3	1
Salamanders	------	1	------	------	------	------	------	------

1/ Does not include salamanders and crayfish.

TABLE 2.--Analysis of variance on the basis of total numbers of organisms in October and November 1952

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between stations--------	1	1,027	1,027	1/ 6.62
Between months----------	1	102	102	------
Interaction-------------	1	62	62	------
Error-------------------	8	1,239	155	------

1/ Significant at 5-percent level.

TABLE 3.--Analysis of variance on the basis of total numbers of organisms in December 1952 and January and February 1953

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between stations--------	1	2,434	2,434	1/ 15.02
Between months----------	2	1,372	686	4.23
Interaction-------------	2	207	104	------
Error-------------------	29	4,706	162	------

1/ Significant at 1-percent level.

high rate of erosion and consequent siltation of the stream channel. Steep grades, lack of allowance for proper drainage, and the proximity of roads to stream channels are particularly conducive to siltation. Also, it is the opinion of many foresters that properly constructed roads, in addition to conserving water values, will, in the long run, pay the logging operator by reducing road maintenance work. Where important fishery values are involved, it is imperative that skid trails and road systems be carefully located and constructed.

Summary

1. From 1942 to 1948, a 212-acre watershed on the Coweeta Experimental Forest, Macon County, North Carolina, was logged by a local contractor. Roads and skid trails were built parallel and adjacent to the stream channel. No surfacing material and no drains were used.

2. The physical and chemical characteristics of Shope Creek, a small trout stream which receives the stream from the logged watershed, are described.

3. During storm periods the turbidity of Shope Creek was appreciably increased by the highly turbid waters from the logged area. The accumulation of sand and silt in Shope Creek below the mouth of the stream from the logged watershed is described.

4. Roads and skid trails proved to be the major source of turbidity. From April 1951 to March 1953, an average of 5.34 cubic feet of soil per lineal foot of road surface was eroded from the logging road.

5. From October 1952 to June 1953, 108 square-foot bottom samples were collected at monthly intervals in Shope Creek at stations above and below the mouth of the stream from the logged watershed.

6. From October 1952 through January 1953, the period of maximum accumulation of sediment in the affected section of Shope Creek, there was a significantly lower standing crop of bottom organisms at the station below the mouth of the logged watershed.

7. A flood on February 21, 1953, removed the accumulation of sand and silt in Shope Creek below the mouth of the logged watershed and reduced the bottom fauna at the lower station to 7.3 organisms per square foot, as compared with 25.5 organisms per square foot at the upper station, which had not been subject to siltation from the logged watershed.

8. The February flood exposed an excellent bottom of rubble and gravel at the lower station; from February through May spring rains and high streamflow prevented the reaccumulation of sand and silt at the lower station on Shope Creek. During this period there was no significant difference in the standing crop of bottom fauna at the control and treated stations. During June, when silt had begun to reaccumulate, the control section again produced a larger standing crop of bottom organisms. The difference was not statistically significant.

Acknowledgments

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STREAM LIFE AND THE POLLUTION ENVIRONMENT*

Alfred F. Bartsch
and
William Marcus Ingram

Increased field investigations over the past 10 years, directed toward the abatement of pollution, have prompted this pictorial presentation to show the impact of pollution upon the stream environment and in turn upon the stream life, or biota. The illustrations were developed initially for use in training sanitary engineers and supporting scientists at the U. S. Public Health Service's Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio.

To show schematically the effects of pollution on biota, raw domestic sewage has been chosen as the pollutant. With such a waste, the lowering of dissolved oxygen and formation of sludge deposits are the most commonly seen of the environmental alterations that damage aquatic biota. Fish and the organisms they feed on may be replaced by a dominating horde of animals such as mosquito wrigglers, bloodworms, sludge worms, rattailed maggots and leeches. Black-colored gelatinous algae may cover the sludge and, as both rot, foul odors emerge from the water and paint on nearby houses may be discolored. Such an assemblage of abnormal stream life urges communities not to condone or ignore pollution, but to abate it without delay. This biotic picture emphasizes that pollution is just as effective as drought in reducing the utility of a valuable water resource. They help to make clear that pollution abatement is a vital key to the over-all problem of augmenting and conserving waters of this land.

No two streams are ever exactly alike. In their individualism streams differ from each other in the details of response to the indignity of pollution. In the following paragraphs, and in the charts they describe, the hypothetical stream is made to conform exactly to theory, showing precisely how an idealized stream and its biota should react in a perfect system. In reality, of course, no stream will be exactly like this although the principles shown can be applied with judgment to actual problems that may be encountered.

ASSUMED CONDITIONS

The stage for discussion is set in Figure 1. The horizontal axis represents the direction and distance of flow of the stream from left to right. Time and distance of flow downstream are shown in days and also in miles. The vertical scale of quantity - or more accurately, concentration - expressed in parts per million, applies to dissolved oxygen and biochemical oxygen demand at distances upstream and downstream from the origin of the sewage discharge, which is identified as point zero. Here, raw domestic sewage from a sewered community of 40,000 people flows to the stream. The volume flow in the stream is 100 cubic feet per second, complete mixing is assumed, and the water temperature is 25°C. Under these conditions the dissolved oxygen (D.O.) sag curve reaches a low point after two and one-quarter days of flow and then

*Originally published with colored illustrations. Editorial changes have been made to make this text conform with the halftone illustrations.

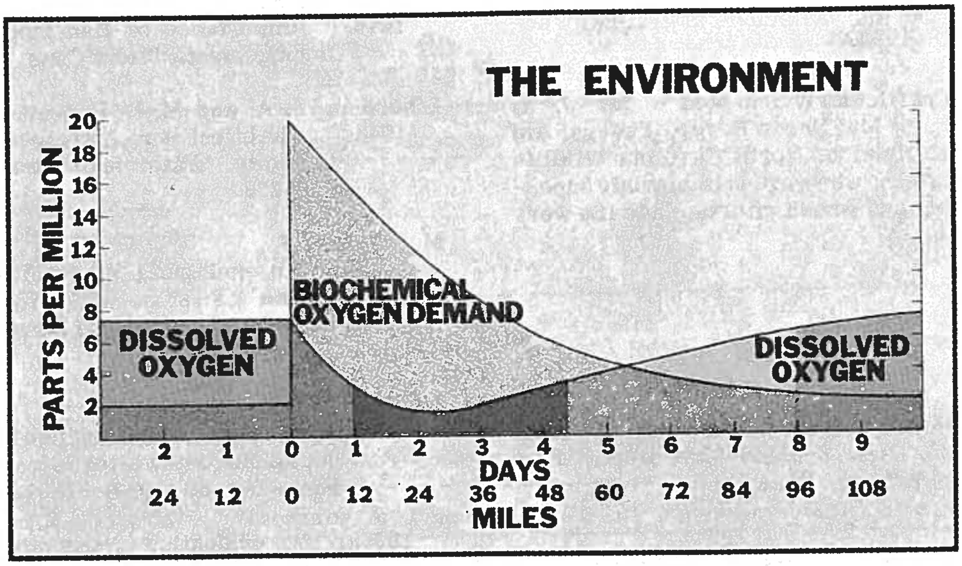

Figure 1 - The assumptions in the hypothetical pollution case under discussion are a stream flow of 100 cfs, a discharge of raw sewage from a community of 40,000 and a water temperature of 25°C, with typical variation of dissolved oxygen and BOD.

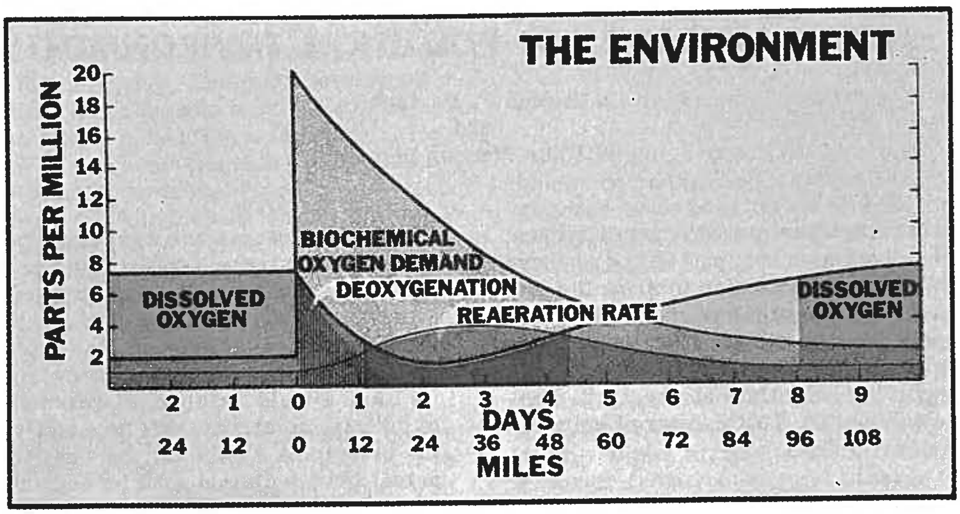

Figure 2 - The dissolved oxygen concentration in the stream is partially destroyed by the pollution load. Full depletion is avoided by reaeration processes.

rises again toward a restoration similar to that of upstream, unpolluted water.

The biochemical oxygen demand (BOD) curve is low in upstream, unpolluted water, increases at point O from the great charge of sewage and gradually decreases from this point downstream to a condition suggestive of unpolluted water. BOD and D.O. are so interrelated that the dissolved oxygen concentration is low where BOD is high, and the converse also is true. From left to right the stream zones are: clean water, degradation, active decomposition, recovery, and clean water.

EFFECTS OF REAERATION

Figure 2 represents an interpretation of the two principal antagonistic factors that have to do with the shape of the D.O. sag curve. The biochemical and other forces that tend to exhaust D.O. supplies, called collectively the process of deoxygenation, would reduce such resources to zero in about a day and one-half if there were no factors in operation that could restore oxygen to water. The river reach where D.O. would be completely gone would occur about 18 miles downstream from the point of discharge of sewage from the municipality. However, with reaeration fac-

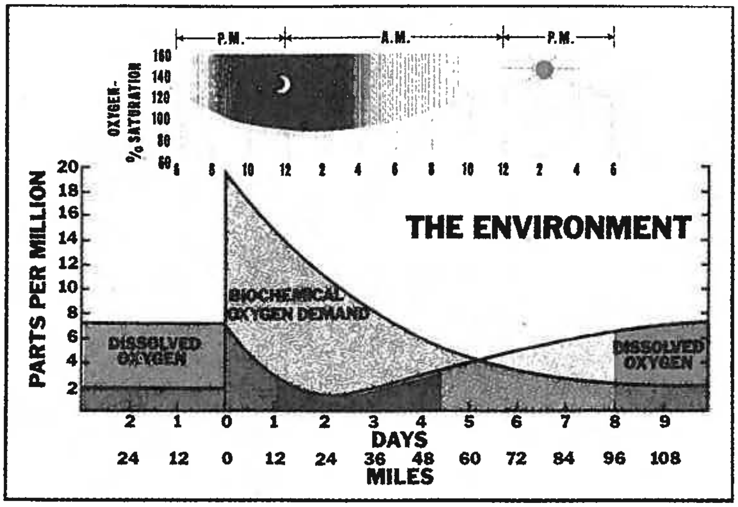

Figure 3 - Dissolved oxygen fluctuates according to available light, a result of photosynthesis. Thus, values on the lower curve are subject to daily variation.

tors at work, there is appreciable compensation for deoxygenation, and in this way the actual contour of the oxygen sag curve is determined. Thus, the low point of the curve is not attained at one and one-half days of flow at mile 18 with a zero D.O., but in reality is reached at about two and one-quarter days of flow at about mile 27. The D.O. here does not go to zero, but to 1.5 ppm.

If the population of the city remains fairly uniform throughout the year, and the flow is relatively constant, the low point of the D.O. sag curve can be expected to move up or down the stream with fluctuations in temperature. In winter, one can expect to find the low point farther downstream than shown. In other seasons, if temperatures exceed the 25°C upon which the charts are based, D.O. will be depleted more rapidly and drastically with the low point farther upstream.

The reach of any stream where the D.O. sag curve attains its low point obviously is the stream environment poorest in D.O. resources. It represents a place where aquatic life that may need a high D.O. can suffocate or from which such life may move to other stream areas where the D.O. resources are greater.

EFFECT OF LIGHT

The upper graph of Figure 3 illustrates fluctuations of dissolved oxygen that may occur over a 24-hour period at a single point in a stream with average density of aquatic greenery such as planktonic algae or larger submerged plants. For sake of explanation, any point in the recovery zone would exhibit such diurnal D.O. variations. The lower graph shows only linear changes in D.O., and gives no indication of the daily variation in availability of this vital gas that may occur at any single selected point.

If this selected point is in the recovery zone at mile 72, one can see from Figure 3 that D.O. varies from a low of about 80 percent saturation at 2:00 a.m. to about 140 percent at 2:00 p.m. Diurnal variation such as this is a result of photosynthesis chiefly in algae but in other plants also. During daylight hours these plants give off oxygen into the water in such large quantities that if the organic wastes are not sufficient to use up much of the D.O. in oxidizing sewage, the water commonly becomes supersaturated at some time during daylight hours. In addition to giving off oxygen, the photosynthetic process results in the manufacture of sugar to serve as the base from which flows the nutritional support for all stream life. The process of photosynthesis can be illustrated schematically as:

$$6\ CO_2 \quad 6\ H_2O \qquad C_6H_{12}O_6 \quad 6\ O_2$$

This action proceeds through the interaction of the green pigment, chlorophyll, contained in living plant matter, of sunlight, carbon dioxide, and even water to form the raw materials into a simple sugar and surplus oxygen.

While photosynthesis occurs, so also does respiration which proceeds 24 hours on end irrespective of illumination. In this well known process O_2 is taken in and CO_2 is given off. The algae, during daylight may yield an excess of oxygen over and above their respiratory needs, the needs of other aquatic life, and the needs for the satisfaction of any biochemical oxygen demand. Under these conditions, surplus oxygen may be lost to the atmosphere. During hours of darkness photosynthesis does not occur and gradually, the surplus D.O. that was present is used up or reduced by algae, fish, various insects, clams, snails and other aquatic life in respiration, and by bacteria in satisfaction of the BOD. That is why oxygen resources are poorest during early morning hours. During hours of darkness, a stream is typically dependent on physical reaeration for its oxygen resources after exhaustion of the "bank of dissolved oxygen," that was elevated to supersaturation levels by aquatic plants.

Obviously, on stream sanitary surveys where or-

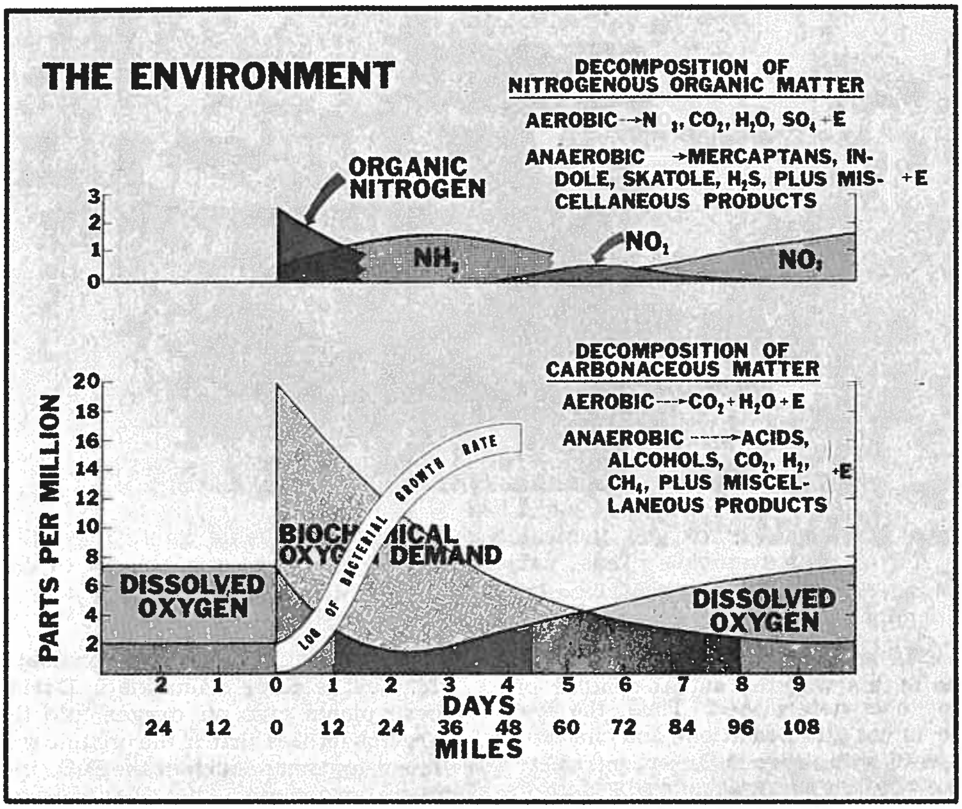

Figure 4 - With a heavy influx of nitrogen and carbon compounds from sewage, the bacterial growth rate is accelerated and dissolved oxygen is utilized for oxidation of these compounds. As this proceeds, food is "used up" and the BOD declines.

ganic wastes such as domestic sewage are pollutants, it is important to sample each station over 24 hours at intervals that are appropriate to reveal information on diurnal D.O. variations. If this is not done and station 1 is sampled consistently around 8:00 a.m. and station 6 around 5:00 p.m. over a weekly or a monthly survey, critical D.O. concentrations will not be found. If interval sampling over 24 hours cannot be done because of workday restrictions, reversing the time of sampling from the upstream to the downstream station on alternate days will at least show variations of D.O. that one can expect through an 8-hour workday.

EFFECT OF ORGANIC MATTER

The bottom graph of Figure 4 illustrates reasons for the decrease in the BOD curve progressively downstream and offers an explanation for the depression in the oxygen sag curve. On this graph there has been superimposed, in white, the shape of the log curve of bacterial growth rate. Accelerated bacterial growth rate is a response to rich food supplies in the domestic raw sewage. During rapid utilization of food, bacteria reproduction is at an optimum, and utilization of D.O. becomes fairly proportional to the rate of oxidation.

The upper graph illustrates, in principle, the progressive downstream changes in nitrogen from the organic form to the nitrate form. It demonstrates the initial high consumption of oxygen by bacteria that are feeding on proteinaceous compounds available in upstream waters in freshly discharged domestic sewage. With fewer and fewer of these compounds left in downstream waters, the BOD becomes reduced and the D.O. increases. Fat and carbohydrate foodstuffs rather than proteins could have been chosen just as well to show this phenomenon.

The nitrogen and phosphorus in sewage proteins can cause special problems in some receiving waters. Experience has shown that increasing the amount of these elements in water can create conditions especially favorable for growing green plants. In free flowing, clear, pebble brooks they appear as green velvety coatings on the stones or as lengthy streamers waving gently in the current. They are not unattractive and even, in the poetry of Nature, are complimented by the name "mermaid's tresses." These plants are not like the troublesome ones which occur mostly in more sluggish streams, impoundments or lakes, especially when they are artificially fertilized by sewage. In the clean brook, they not only are attractive and natural to see, but also they are a miniature jungle in which animals of many kinds prey upon each other with the survivors growing to become eventual fish food.

In more quiet waters, the algal nutrients in sewage are picked up for growth by less desirable kinds of algae. With great supplies of nitrogen and phosphorus made available, free-floating, minute blue-green algae increase explosively to make the water pea soup green, smelly and unattractive. In some unfortunate local-

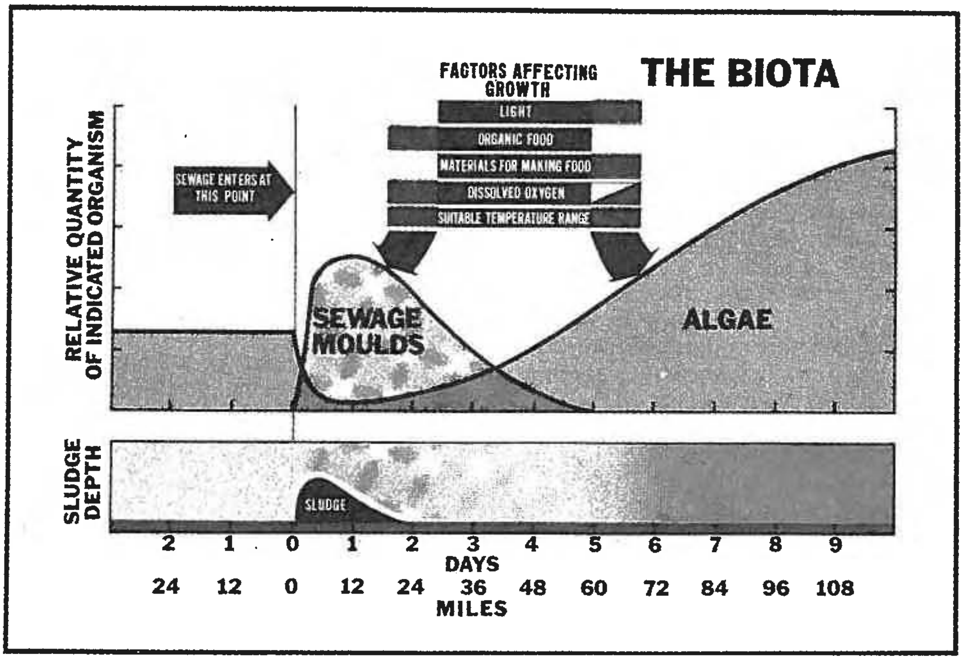

Figure 5 - Shortly after sewage discharge, the moulds attain maximum growth. These are associated with sludge deposition shown in the lower curve. The sludge is decomposed gradually; as conditions clear up, algae gain a foothold and multiply.

ities, nuisance blooms of algae have become so objectionable that waterfront dwellers have had to forsake their homes and see their property depreciate in value. The problem has been studied at a number of localities, and some studies are still in progress. Special legislation has even been formulated requiring that sewage treatment plant effluents not be discharged to susceptible lakes solely because of the algal nutrients they contain. Sometimes, under conditions not well understood, some blue-green algae develop poisons capable of killing livestock, wildlife and fish. Fortunately, such occurrences are rare. It is completely clear that sewage disposal and biological responses of even such lowly plants as algae go hand-in-hand sometimes to plague the desires of man.

AQUATIC PLANTS

In the lower part of Figure 5 a profile is shown of the water and stream bed with the vertical scale of the latter exaggerated. Sludge deposits begin to accumulate just below the point of sewage discharge. These deposits reach their maximum thickness near the point of origin but blanket the stream bed for many miles downstream. The substance of the deposits gradually is reduced by decomposition through the action of bacteria, moulds and other sludge-dwelling organisms, until it becomes insignificant about thirty miles below the municipality.

Also, at the outfall the water is turbid from fine solids held in suspension in the flowing water. Larger floating solids, destined to sink eventually to the stream bed as settleable solids, are visible on the water surface as they drift downstream. Both the fine and large solids contribute to the sludge deposit, and as they settle progressively to the bottom of the stream bed, the water becomes clear and approaches the color and transparency of upstream water above the point of sewage discharge.

The upper graph illustrates the relative distribution and quantities of algae, various moulds, and filamentous bacteria such as Sphaerotilus. From mile 0 to mile 36, high turbidity from floating debris and suspended solids is not conducive to algal production. Thus, except for slimy blue-green marginal and bottom types, algae are sparse in this reach. In order to grow well algae need sunlight, and here it cannot penetrate the water effectively. Also, floating solids that settle out of the water carry to the bottom with them floating algae that drift into the polluted zone from clear water areas upstream.

Blue-green algae that may cover marginal rocks in slippery layers and give off foul odors upon seasonal decay masquerade under the names: Phormidium, Lyngbya, and Oscillatoria. Green algae that accomodate themselves to the putrid zone of active decomposition frequently include Spirogyra and Stigeoclonium. Gomphonema and Nitzschia are among the diatoms that are present here.

Algae begin to increase in numbers at about mile 36. Plankton, or free-floating forms, steadily become more abundant and reach their greatest numbers in algal blooms some 40 to 60 miles farther downstream. This is where reduced turbidity, a lack of settleable sewage solids, final mineralization of proteinaceous organics to nitrate-nitrogen fertilizers, and favorable oxygen relations result in an ideal environment for growth of abundant aquatic plants.

Algae that may be found abundantly here may be represented by the bluegreen genera Microcystis and Anabaena; the pigmented flagellates are represented by Euglena and Pandorina; the green algae by Cladophora, Ankistrodesmus, and Rhizoclonium; and diatoms by Meridion and Cyclotella. Rooted, flowering, aquatic plants that form underwater jungles here are represented by the "water pest." Elodea, and various species of pond weeds known as Potomogeton. Such aquatic forests and meadows present an excellent natural food supply for the aquatic animals, and also serve them with shelter. Thus, commonly as plants respond downstream in developing a diversified population in the recovery and clean water zones, animals follow a parallel development with a great variety of species. In such reaches where the stream consists of numerous alternating riffles and pools, a great variety of fish are likely to occur.

In the reach where algae are scare (sic: scarce), from about 0 to mile 36, various moulds and bacteria are the dominant aquatic plants. Sphaerotilus filaments may abound in riffle areas at about mile 36 where physical attachment surfaces are available and where oxygen, although low, is adequate. Bacterial slimes may cover rocks and other submerged objects and bank margins. Such slimes have an abundant supply of available food in readily usable form of carbohydrates, proteins and fats and their digestion products. They are not bothered especially by high turbidities or by settleable solids. They do well living in the center of sludge or near it, in what to them is an "apple-pie" environment.

BACTERIA AND THE CILIATES

Associated with the bacterial slimes are certain ciliated protozoans that feed on bacteria and engulf small particles of settleable organic matter. Such ciliates are also found in aeration tanks of sewage treatment installations as a component of activated sludge and on the surface of rock in trickling filter beds. Common ones are Epistilis, Vorticella, Colpidium, and Stentor.

Figure 6 illustrates the interrelations between bacteria and animal plankton, such as ciliated protozoans, rotifers and crustaceans. The quantities shown and the die-off curves for sewage bacteria in toto and for coliform bacteria separately are theoretically accurate. The center curve for ciliated protozoans and the last curve representing rotifers and crustaceans are more accurate in principle than in actual quantities.

After entering the stream as a part of the sewage, bacteria, including coliforms, reproduce to become abundant in an ideal environment. Here they feed on the rich organic matter of sewage and by multiplying rapidly offer a ready food supply for ciliated protozoans which are initially few in number. After about a day of flow the bacteria may be reduced through natural die-off and from the predatory feeding by protozoans. After about two days of flow, the stream environment becomes more ideal for the ciliates, and they form the dominant group of animal plankton. After seven days, the ciliates fall victim to rotifers and crustaceans which represent the principal microscopic animal life in the stream.

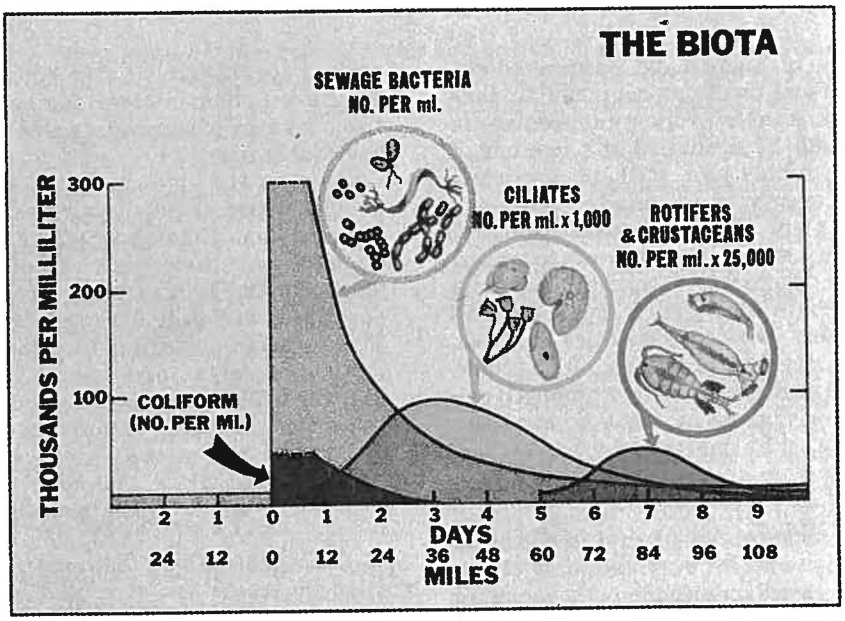

Figure 6 - Bacteria thrive and finally become prey of the ciliates, which in turn are food for the rotifers and crustaceans.

It has been long suspected that the efficiency of this sewage consuming biological machine depends upon a close-knit savage society in which one kind of organism captures and eats another. Classical research of some time past showed that a single kind of bacterium mixed with sewage in a bottle could not do an efficient or rapid job of breaking down the sewage. Several kinds could do a better job, supposedly because one bacterial type, in acting upon parts of the sewage as food, prepared it for acceptance by another. With several bacteria a multilateral attack was made possible. But even a system like this is inefficient. Bacteria work best only when they are growing rapidly and they do this when they multiply frequently by splitting into two. It is important then that they not be permitted to attain a stable high and lazy population. In the bottle the task of stabilizing sewage goes most rapidly when ferocious bacteria-eating ciliates are introduced to keep the population at a low and rapidly growing state.

These relations between the bacteria eaters and their prey, discovered in the bottle, apply as well to efficient functioning of a modern sewage treatment plant. In some sewage treatment plants, examination is made routinely to see how the battle lines are drawn up between the bacteria eaters and their prey. It now becomes more obvious why sewage disappears so efficiently from the stream. It also is clear why the bacteria, the ciliates, the rotifers and the crustaceans increase, persist for awhile, and then decrease along the course of passage of the stream.

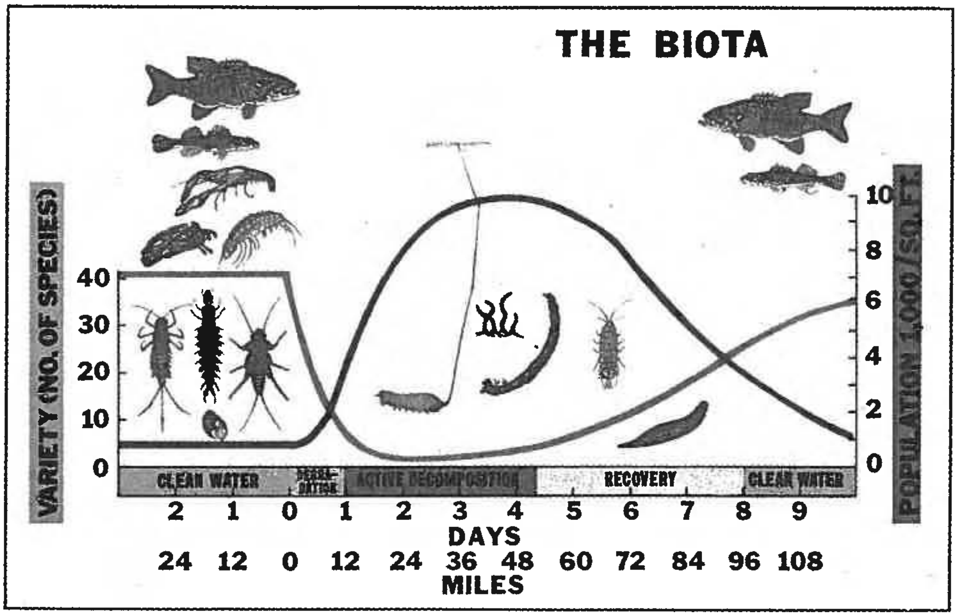

Figure 7 - The [upper] curve shows the fluctuations in numbers of species: the [lower] the variations in numbers of each.

THE HIGHER FORMS

Figure 7 illustrates the types of organisms and the numbers of each type likely to occur along the course of the stream under the assumed physical conditions that were stated earlier. The upper curve represents the numbers of kinds or species of organisms that are found under varying degrees of pollution. The lower curve represents the numbers of individuals of each species. In clean water above the city a great variety of organisms is found with very few of each kind represented. At the point of waste entry the number of different species is greatly reduced, and they are replaced by a different association of aquatic life. This new association demonstrates a severe change in environment that is drastically illustrated by a change in the species make-up of the biota. However, this changed biota, represented by a few species, is accompanied by a tremendous increase in the numbers of individuals of each kind as compared with the density of population upstream.

In clean water upstream there is an association of sports fish, various minnows, caddis worms, mayflies, stoneflies, hellgrammites, and gill-breathing snails, each kind represented by a few individuals. In badly polluted zones the upstream association disappears completely or is reduced, and is replaced by a dominant animal association of rattailed maggots, sludge worms, bloodworms and a few others, represented by great numbers of individuals. When downstream conditions again resemble those of the upstream clean water zone, the clean water animal association tends to reappear and the pollution tolerant group of animals becomes suppressed. Thus, clean water associations of animals may form parameters around polluted water reaches. Such associations may be indicative that water is fit for multiple uses, while the presence of a pollution tolerant association of animals indicates that water has restricted uses.

Pollution tolerant animals are especially well adapted to life in thick sludge deposits and to conditions of low dissolved oxygen. The rattailed maggot, Eristalis tenax, is not dependent on oxygen in water. This animal shoves its "snorkle-like" telescopic air tube through the water surface film to breathe atmospheric oxygen. Thus, even in the absence of oxygen it is one of the few survivors where most animals have suffocated. Those who have worked around sewage treatment installations have probably observed the flesh or milkish colored rattailed maggot in the supernatant over sludge beds where dewatering performance was poor. Commonly associated with it in this supernatant over sludge beds are the immature stages of the well-known "sewagefly," Psychoda, and wrigglers of the sewage mosquito, Culex pipiens. The rattailed maggot turns into a black and brownish banded fly about three-quarters of an inch long, called a "bee fly" because it closely resembles a bee. It differs by having two wings instead of four and does not sting. Sludge worms, Tubifex, are dependent upon the dissolved oxygen in water; however, they are well adjusted to oxygen famine and commonly are found in water with as little as half a part per million. They are actually aquatic earthworms, cousins of the terrestrial earthworms found in lawns and used as fish bait. These worms feed on sludge by taking it into the digestive tract. In passing it through their alimentary canal, they remove organic matter from it, thus reducing the biochemical oxygen demand. Sludge worms one and one-half inches long and as thick as a needle have been observed to pass fecal pellets totaling five feet nine inches through the digestive tract in 24 hours. Fecal pellets that are extruded from the anal openings have on occasion been found to have a biochemical oxygen demand of one-half of that of sludge that was not "worked-over" by them. The sludge worms are then, "actually crawling BOD," in that they incorporate sugars, proteins and fats that are present in sludge into their body cellular components. It may be difficult to visualize the magnitude of BOD removal that one worm, needle-thick in size and one and one-half inches long, can accomplish in relation to an extensive sludge deposit. However, when it is realized that from 7,000 to 14,000 of these worms may be found per square foot of bottom surface in sludges, considerable work is done in removing BOD. By the same token, for example, wrigglers of sewage mosquitoes. (Sic. ,) Culex pipiens, that feed on the organics of sewage and emerge as adults to fly out of water represent BOD removed. In this instance it is "flying COD" that is factually taken out of water, whereas the crawling BOD of sludge worms is not removed, but is recycled back as the worms die.

The worm-like body of organisms composing the pollution tolerant association of the rattailed maggot, sludge worms, blood worms, and leeches is an ideal type to have for successful living in sludge. As settleable solids fall to the bottom, such organisms are not trapped and buried in them to die, but by wriggling with their worm-like cylindrical bodies, manage to maintain their position near the surface of sludge in communication with the water interface. Sow-bugs that are shown in Figure 7 with the "wormy-horde" do have well-developed appendages, but their life may be marginal on stream bank areas and on the surface of rocks protruding from sludge covered bottoms. Thus, they are not buried by settleable solids.

The invertebrates shown in clean water do not form successful populations in streams where settleable solids sink to form sludge deposits. Because their appendages may become clogged with sludge as solids settle, they may be carried readily to the bottom and be buried alive.

POPULATION FLUCTUATION

Figure 8 shows that the population curve of Figure 7 is actually composed of a series of population maxima for individual species. The species form a significant pattern in reference to each other and to the varying strength of the pollutant as it decreases progressively downstream. Sludge worms such as Tubifex and Limnodrilus can better withstand pollution than other bottom invertebrates. Thus, they reach great numbers closer to the source than other bottom dwelling animals. In turn they are replaced in dominance by red midges, also called bloodworms or Chironomids, and then by aquatic sow-bugs, Asellus. The sludge worms and red midges are so numerous in contrast to the other organisms shown in Figure 8 that

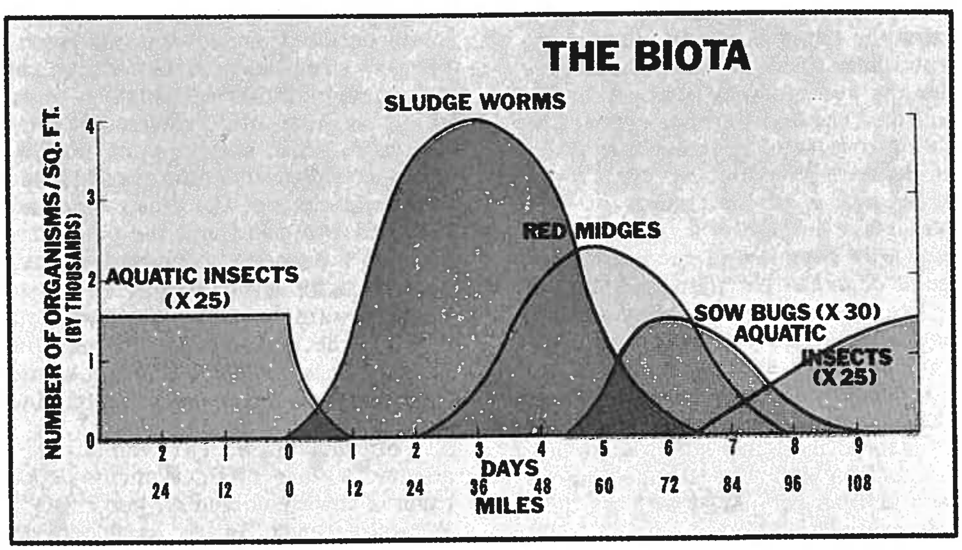

Figure 8 - The population curve of Figure 7 is composed of a series of maxima for individual species, each multiplying and dying off as stream conditions vary.

numbers of the latter are exaggerated 25 to 30 times to permit showing them effectively. Finally, when the effects of pollution have largely subsided in the environment, a variety of insect species represented by few individuals of each dominates the bottom habitat.

The story of pollution told here emphasizes that stream pollution and recovery may follow an orderly scheme under the influence of interacting physical, chemical and biological forces. Using streams as dumping places for sewage triggers the environmental and biotic changes that have been shown. These changes are not desirable. In most cases, in addition, they are hazardous to public health and otherwise impair the usefulness of valuable water resources. The needed remedy is to confine all of these interacting forces in an acceptable sewage treatment works so that this example of the Nation's water resources is protected for present and future use.

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