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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

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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 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 biodynamic 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 tests, 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

BY ARDEN R. GAUFIN AND CLARENCE M. TARZWELL

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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 fish-life 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 usable. 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 macroinvertebrate 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.