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BIOLOGICAL INDICES OF WATER POLLUTION, WITH SPECIAL REFERENCE TO FISH POPULATIONS[1]

by

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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

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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 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 over-simplification of the problem. It must be admitted that probably nobody has come forth yet with a clear statement of this claim. And 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 consistentely 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 terminiology 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 quotation 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 questionable. 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 good 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 I-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 own existence.

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