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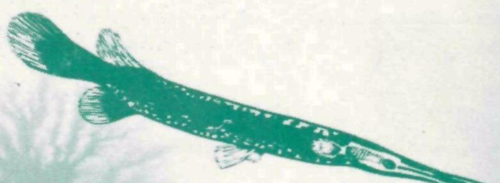
POLLUTION AND THE LIFE IN WATER



DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

POLLUTION AND THE LIFE IN WATER

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ABSTRACT

The study of aquatic organisms as they have been related to water supply and water pollution problems since 1850 is detailed. Significant contributions have been made that relate plankton, benthos, periphyton, and fish to the definition of organic, toxic, thermal, and silt pollution. Generally it is not realistic to isolate a particular genus or even a species of aquatic organism to indicate the presence or absence of pollutional wastes in water. It is the study of the total aquatic biota that tells one most about water conditions. Nevertheless, something equated with the magnitude of the problem that may be termed "reality" often dictates the type of study and the kinds and numbers of samples collected.

Serious thought should be given in the reporting of data to ensure that the final report is matched to the needs of the study and provides answers to questions responsible for the instigation of the study. (3 figures, 73 references)

POLLUTION AND THE LIFE IN WATER*

CHRONICLE

Since the turn of the century, and even before, biologists have struggled to determine the impact of civilization's rejectamenta on aquatic biota and to explain these phenomena to their associated disciplines and to the public. The chronicle of published effort began with Hassall in 1850 (1850, 1856) who noted the value of microscopic examination of water for the understanding of water problems. Sedgwick (1888) led in application of biological methods to water supply problems. The Massachusetts State Board of Health was the first agency in the United States to establish a systematic biological examination of water supplies. In 1889 Sedgwick collaborated with George W. Rafter to develop the Sedgwick-Rafter method of counting plankton. Whipple (1899) produced a treatise that, in 1948, was in its fourth edition and fifth printing; it has served through the years as an often-used reference in the water supply and water pollution field.

One of the first practical applications of biological data to the biological definition of water pollution was contained in the "saprobien system" of Kolkwitz and Marsson (1908, 1909). This system, based on a check list detailing the responses of many plants and animals to organic wastes, has been extensively used to indicate the degree of pollution at a given site. That the sound basic judgment of these early investigators has withstood the passage of time is shown by the frequent references currently made to their works.

The survey of the Illinois River by the Illinois Natural History Survey was one of the first that clearly demonstrated the biological effects of organic pollution; a series of papers represents studies that provided much impetus and professional status to biological stream investigations in the United States (i.e., Forbes and Richardson, 1913, 1919; Forbes, 1928). Richardson (1921) showed that changes had occurred in the bottom fauna of the Illinois River since 1913 as a result of the increased movement of sewage pollution southward. Later, Richardson (1928) noted that "...the number of small bottom-dwelling species of the fresh waters of our distribution area that can be safely regarded as having even a fairly dependable individual index value in the present connection is surprisingly small; and even those few have been found in Illinois to be reliable as index species only when used with the greatest caution and when checking with other indicators."

*** Presented at: Pymatuning Laboratory of Field Biology of University of Pittsburg by Kenneth M. Mackenthun, July 17, 1964.**

Purdy (1916) demonstrated the value of certain organisms for indicating areas of the Potomac River receiving sewage discharges. The shallow flats of the Potomac River were found to be of great importance in the natural purification of organic wastes; sunlight and turbidity were observed to be prominent factors in the determination of oxygen levels and in waste purification processes. Weston and Turner (1917), Butterfield (1929), and Butterfield and Purdy (1931) reported other studies that demonstrated the effects of organic enrichment on a stream, the sudden change in the biota after the introduction of the waste, and the progressive recovery of the biota downstream as the wastes were utilized.

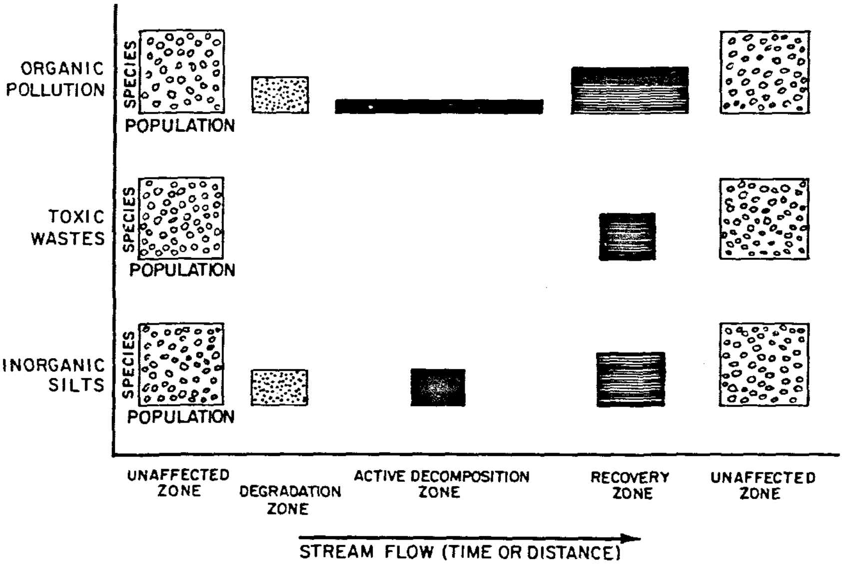

Figure 1. Response of benthos to pollution.

Butcher (1932, 1940) studied the algae of rivers in England and noted that attached algal forms gave the most reliable indication of the suitability of the environment of an area for the support of aquatic life. In the United States, Lackey (1939, 1941a, 1942) worked with planktonic algae and noted their response to various pollutants. The work of Ellis (1937) on the detection and measurement of stream pollution, the effects of various wastes on stream environments, and the toxicity of various materials to fishes has served as a reference handbook and toxicity guide through many years.

Cognizance has been taken of the biotic community and the effect of pollution on the ecological relationships of aquatic organisms (Brinley, 1942; Bartsch, 1948). Bartsch and Churchill (1949) graphically depicted (Figure 1) the biotic response to stream pollution and related stream biota to zones of degradation, active decomposition, recovery, and clean water. Patrick (1949) described a healthy stream reach as one in which "...the biodynamic cycle is such that conditions are maintained which are capable of supporting a great variety of organisms," a semihealthy reach as one in which the ecology is somewhat disrupted but not destroyed, a polluted reach as one in which the balance of life is upset, and a very polluted reach as one that is definitely toxic to plant and animal life. Patrick separated the biota into seven groups and demonstrated specific group response to stream conditions by bar graphs. The number of species was used rather than the number of individuals. Fjerdingstand (1950) published an extensive list placing various algae and diatoms in zones or in ranges of stream zones similar to those of Kolkwitz and Marsson.

ORGANISM RESPONSES

The "classical" benthic organism responses to organic wastes have been detailed frequently in the literature (Hynes, 1960; Biglane and Lafleur, 1954; Hirsch, 1958; Dymond and Delaporte, 1952; Pentelow, 1949; Van Horn, 1949, 1952; Bartsch and Ingram, 1959; and Gaufin, 1958). Benthic organisms are directly subjected to adverse conditions of existence as a result of their preferred habitat and their general inability to move great distances by self motion. Different types of organisms respond in a variety of ways to changes that may occur in their environments. Some species cannot tolerate any appreciable water quality changes, whereas others can tolerate a wide range of water quality, and some very tolerant ones are able to live and multiply under extremely adverse environmental conditions. Generally, a natural, unpolluted stream reach will support many different kinds of organisms but relatively few individuals of a given species because of predation and competition for food and living space. The converse most often exists in a stream reach polluted with organic wastes. In such a reach, most predators are eliminated by water quality or substrate changes, living space presents no problem because remaining organisms must be well adapted to live in organic sludge, and food is seemingly inexhaustible. Sludgeworm populations have, on occasion, been calculated to exceed 50,000 pounds per acre of stream bottom.

Patrick (1953) listed five conditions caused by wastes that may be harmful to aquatic life: dissolved-oxygen deficiency, toxicity, extreme temperature changes, harmful physical abrasion, and deposits that render the bottom substratum untenable for habitation.

Gaufin and Tarzwell (1952, 1956) described extensive studies of Lytle Creek, which received organic pollution. In the septic zone it was found that 40 percent of the benthic population was Diptera, 20 percent Coleoptera, 20 percent segmented worms, 10 percent Hemiptera, and 10 percent Mollusca. All insects were characterized by having some means of using atmospheric oxygen. Hawkes (1963) observed that the riffle community is remarkably sensitive to changes in the organic loading of the water, and since organic and mineral matter and organisms are constantly being lost by the streambed community, most stream communities rely on sources outside the stream itself for their basic materials. Butcher (1959) stated that with gross organic pollution the flora of a river consists of "sewage fungus," and the fauna, of tubificid worms and Chironomus larvae. As the organic matter decomposes (with increasing distance from the source of pollution), Asellus replaces Chironomus, then mollusks appear, and finally caddisfly larvae and fresh-water shrimp.

Ingram (1957) discussed the pollutional index value of mollusks and stated that "Apart from systematic morphological studies, it is not realistic to isolate a single group of organisms such as mollusks from other animals and plants that are associated under similar ecological conditions in clean or polluted water. It is the study of the total biota which tells one most about water conditions."

Groups of related organisms have, however, been used to indicate water quality. Palmer (1957) stated that "...it appears evident to many workers that particular genera or even species of algae, when considered separately, are not reliable indicators of the presence or absence of organic wastes in water. However, when a number of kinds of algae are considered as a community, that group may be reliable as such an indicator." Lackey (1941b) listed a number of algae that thrive best in polluted water. Patrick (1957) stated that diatoms are a desirable group for use to indicate stream conditions because they need no special treatment for preservation. The diatom flora of a normal stream is made up of a great many species and a great many individuals, and diatoms as a group vary greatly in their sensitivity to chemical and physical conditions of water. She also concluded (Patrick, 1948) that the attached forms give the most reliable indication of the suitability of the environment for the support of aquatic life.

Czensny (1949) observed the effects of different types of pollution on fish, on fish food, and on the over-all fisheries resource. Doudoroff and Warren (1957) stated that "...only fish themselves can be said to indicate reliable environmental conditions generally suitable for their own existence." Katz and Gaufin (1953) studied the effects of sewage pollution on the fish population of a midwestern stream and concluded that the presence of black bass and darters is good evidence that organic pollution is not a major limiting factor in an area. Mills (1952) stated that the fish population itself is the index or pointer to the other small forms that need to be considered. Katz and Howard (1954) found a significant difference in the length of fish of the same year-class in the various pollutional zones, with the greatest length attained in the enriched lower portion of the recovery zone. In this study, no relation between growth of fishes and volume of bottom organisms was apparent.

Toxic wastes have a severe impact on aquatic biota. Notwithstanding the variation in response to a specific concentration of a toxicant among aquatic animals and plants, a toxic substance eliminates aquatic biota until dilution, dissipation, volatilization, etc., reduce the concentration below the toxic threshold (see Figure 2). There is no sharp increase in certain forms as there is with organic wastes; rather there is an abrupt decline in both species and population followed by a gradual return to normal stream inhabitants at some point downstream. The bioassay is, therefore, an important tool in the investigation of toxic effluents.

The effects of inert silts on the benthos is similar to those of toxic wastes, but usually not so severe. Generally, both the number of species and the total population following silt pollution (Cordone and Kelley, 1961) are depressed. The algal population is also often much reduced from the population occurring in areas not laden with silt.

Lakes and other standing waters do not usually support the variety of benthos found in streams. As with streams, however, organic pollution eliminates many benthic forms and results in population increases among the more tolerant varieties (Surber, 1953). Surber (1957) stated that "A survey of the lake reports showed that an abundance of tubificids in excess of 100 per square foot apparently truly represented polluted habitats." Changes in the benthic population structure are especially evident in the alluvial fans produced in lakes by polluted influent streams (see Figure 2). Along with changes in the benthos, the nutrients contributed by organic pollution may stimulate aquatic growths that will have a severe impact on the recreational use of the water. Resultant algal blooms concomitant with recycling and reuse of nutrients within the lake basin contribute to and hasten inevitable eutrophication.

The estuarine and marine environments have not been studied as extensively as the fresh-water habitats. Reish (1960) cited Wilhelm (1916) to the effect that the polychaete Capitella capitata (Fabricius) plays a role in marine waters similar to that the oligochaete Tubifex plays in fresh water. Filice (1954) and Reish (1960) found three benthic zones surrounding a major pollutional discharge: one essentially lacking in animals, an intermediate zone having a diminished fauna, and an outer zone unaffected by the discharge. Filice (1959) found the crab Rhithropanopeus harrisii (Gould) present more abundantly than expected near industrial outfalls; this crab and Capitella capitata (Fabricius) were present in large numbers near domestic outfalls. Hedgpeth (1957) reviewed the biological aspects of the estuarine and marine environments.

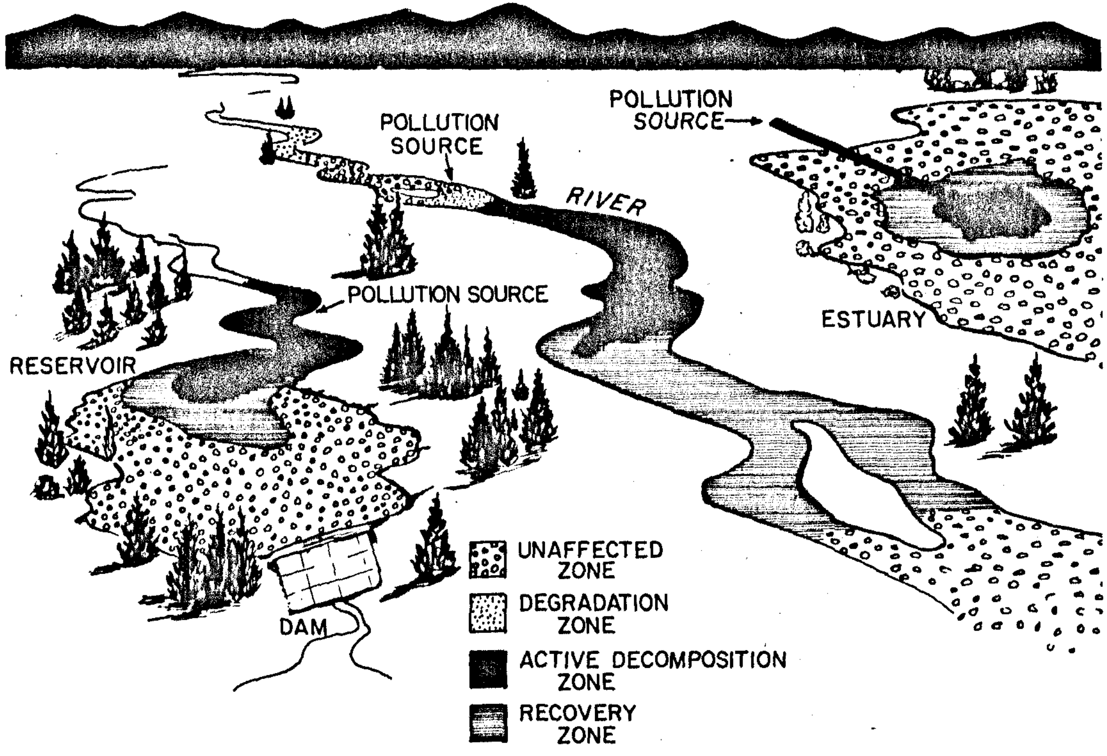

Figure 2. Benthic zones of pollution (organic wastes).

Biological surveys may be tedious, time consuming, specialized, demanding, and sometimes expensive, but they are never monotonous and are seldom routine. Surveys can involve many facets of the aquatic biota or they may concentrate on one group of organisms (see Figure 3).

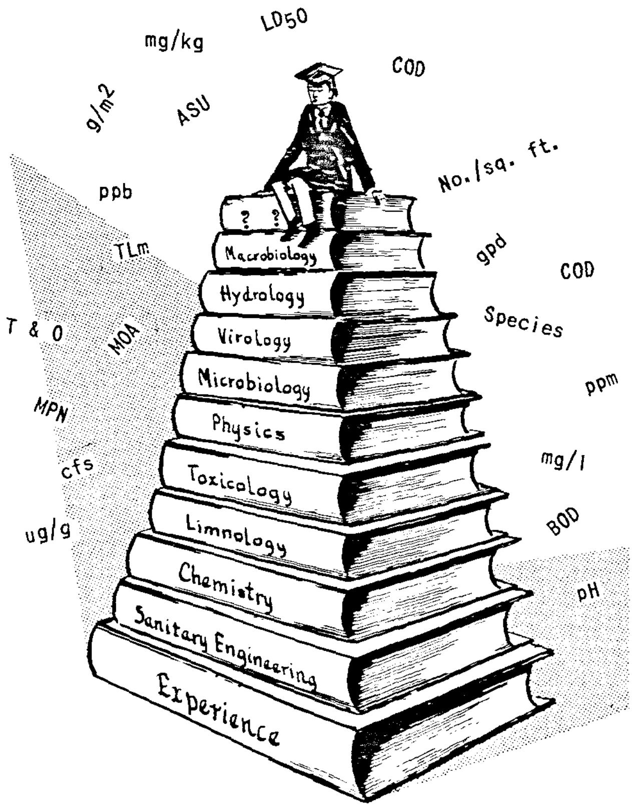

Figure 3. Pollution evaluation requires a solid foundation supplied only by interrelating many disciplines.

Something that may be termed "reality," equated with the magnitude of the problem, most often dictates the type of study and the kinds and numbers of samples to be collected. To those faced, for example, with an administrative request for a report in 3 weeks on 100 miles of stream with 30 outfall sewers clustered within a metropolitan area, reality dictates the extent and scope of field studies. Biological sampling downstream from each outfall would not be feasible and indeed it would not be biologically possible to distinguish among many of those outfalls in close proximity to each other.

Excluding routine plankton collections, a biologist should always collect his own samples. Nowhere in the sanitary sciences is more sound field judgment required than that required of the biologist in taking his samples and in observing the environment from which the sample came. Much of his field value lies in his astute observation of change within the growth patterns of those biota subject to any adversities within the environment.

Many streams, because of their physical makeup, do not lend themselves to benthic sampling with routine tools such as the Ekman dredge, Petersen dredge, and Surber square-foot sampler. Cooke (1956) reviewed the literature on colonization of artificial bare areas; Scott (1958) described sampling with brush boxes in nonproductive stream areas; and Hester and Dendy (1962) described the use of a multiple-plate sampler made from 3-inch masonite squares separated on a rod by 1-inch masonite squares. The multiple-plate sampler has been found to be an effective tool in several streams throughout the United States. Lund and Talling (1957) and Sladeckova (1962) described sampling methods for the algal and periphyton communities. Many sampling procedures and techniques were detailed by Welch (1948). The biologist should relate all routine sampling procedures to Standard Methods for the Examination of Water and Waste-water (APHA, 1960), or his report should contain a description of those techniques that differ.

SELLING THE PRODUCT

Too often the vital message that biology can bring to the definition of the pollution problem has been lost because of the obscurity of presentations sprinkled liberally with vague generalities and because of lack of understanding and appreciation of the language used to couch the message. Often basic facts become mired in technical explanation. The biologist presently must travel more than halfway if he is to sell the products of his science to the reader. Good, concise, assertive reporting supported by uncluttered, pertinent graphical material does much to please and stimulate the reader to greater comprehension of the findings of fact. One of the biologist's challenges is to present information that is understandable, meaningful, and helpful to associated disciplines, to administrators, and to the general public who are the financial supporters as well as the benefactors of a pollution abatement program.

Recently several methods have been proposed for the presentation of biological data. Beck (1954, 1955) grouped benthic organisms into five classes based on their sensitivity to environmental change and proposed a numerical biotic index that represented a summation of those species that tolerate no appreciable pollution and those that tolerate only a moderate amount. Beak (1963) modified Beck's reporting method to include three groups in which all occurring species are placed: those very tolerant of pollution, those occurring in both polluted and unpolluted situations, and those intolerant of pollution. Points are arbitrarily assigned to each group, and a biological score results from adding the points at a given station.

Wurtz (1955) developed for each station a four-column histogram in which the columns represent basic life forms: burrowing organisms, sessile organisms, foraging organisms, and pelagic organisms. Columns are plotted as a frequency index in which the total number of species found at any station represents a frequency of 100 percent for that station.

Beak et al. (1959) used bivariate control charts to describe changes in benthos adjacent to the site of a large chemical plant. Burlington (1962) statistically calculated a "coefficient of similarity" among stations; for each specific group of organisms, he used "prominence values" that take into account both density and frequency of observation. Patrick and Strawbridge (1963) stated that it is relatively easy to determine the presence of large amounts of pollution, but that the determination of definite but borderline deterioration of water quality is in some cases difficult. They presented a mathematical method whereby the limits in variation of natural populations, especially diatoms, can be defined.

Ingram and Bartsch (1960) pleaded for the use of common, understandable terms in presentations on biology. They pointed out the value of photographs to depict unusual environmental conditions and showed a number of different graphical presentations used in investigational reports.

Serious thought should be given the methods and techniques of reporting data to ensure that the final report meets the needs of the study and provides answers to questions originally responsible for the initiation of the study. Often less thought and consideration are given to reporting data than to collection and analyses of data, even though each is equally important to a successful contribution.

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