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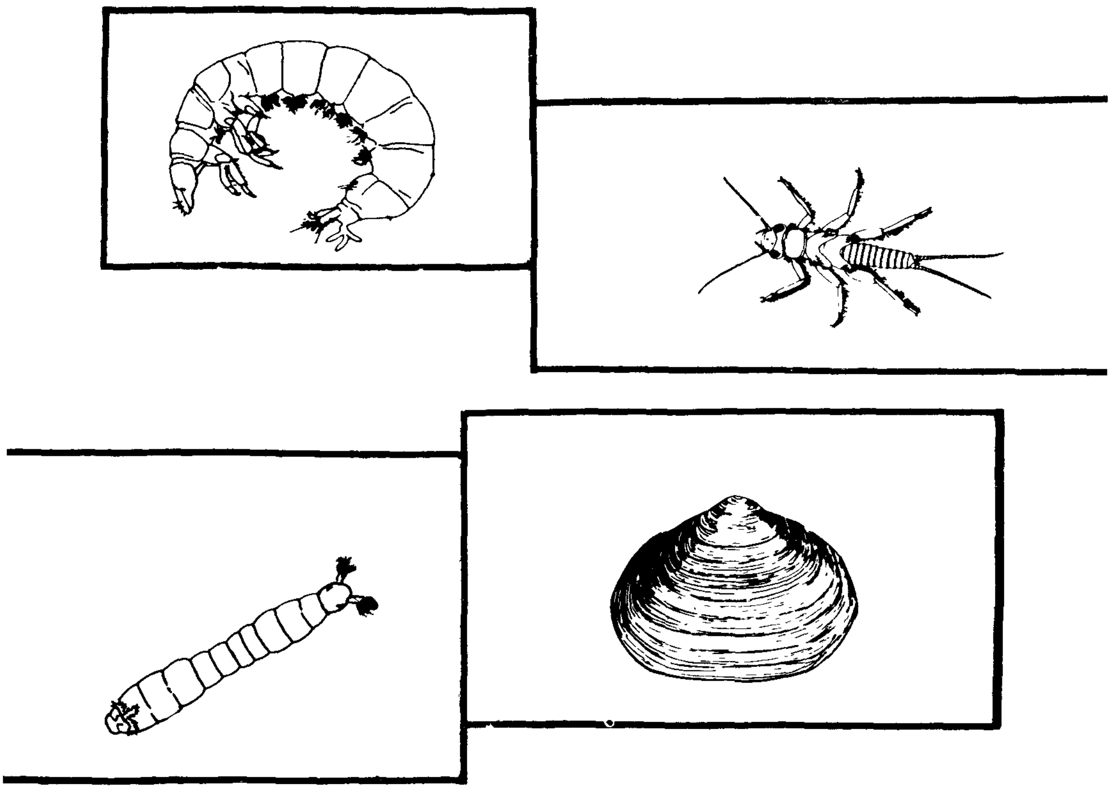
BOTTOM-DWELLING MACROFAUNA IN WATER POLLUTION INVESTIGATIONS



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

THE ROLE OF BOTTOM-DWELLING MACROFAUNA IN WATER POLLUTION INVESTIGATIONS

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CONTENTS

ABSTRACT

The authors evaluate the use of bottom-dwelling animals in water pollution abatement programs. How and why the bottom-dwelling fauna exhibit pollution-induced changes and the factors involved in data collection, interpretation, and evaluation are discussed. A bibliography on the theory and applied use of bottom-dwelling animals in pollution evaluation is included.

THE ROLE OF BOTTOM-DWELLING MACROFAUNA IN WATER POLLUTION INVESTIGATIONS*

INTRODUCTION

Water pollution evaluation is complicated, but basically it is a measure of pollution's impact on the environment routinely accomplished through biological, chemical, physical, and engineering determinations.

Polluting materials may transmit disease organisms, create nuisances, and adversely affect water supplies, recreation, and biological resources, as well as the aesthetic qualities of water. Rarely does pollution affect one of these independent of the others.

Biology plays a prominent role in all stages of water pollution abatement: (1) assessing damages, (2) determining the cause of damages, and (3) solving the problem. A biological survey can determine the effects of pollution and can aid in identifying the source and in establishing the specific cause. Solution of the problem is the definitive act and involves the removal or reduction of the damaging agents so that multiple water uses are not curtailed. Biology can and must contribute to the solution by assessing how much of the causative agent needs to be eliminated to reduce the damages to an acceptable level.

Complete biological analyses of the aquatic environment involves an interpretative study of the physical and chemical environmental relationships among man, bacteria, fungi, algae, invertebrates, fishes, and wildlife.

BOTTOM-DWELLING FAUNA

Bottom-dwelling fauna are animals that live directly in association with the bottom of a waterway (Figure 1). They may crawl on, burrow in, or attach themselves to the bottom. Macroorganisms are usually defined as those organisms that will be retained by a No. 30 sieve.† In essence, the organisms retained by the sieve are those that are visible to the unaided eye.

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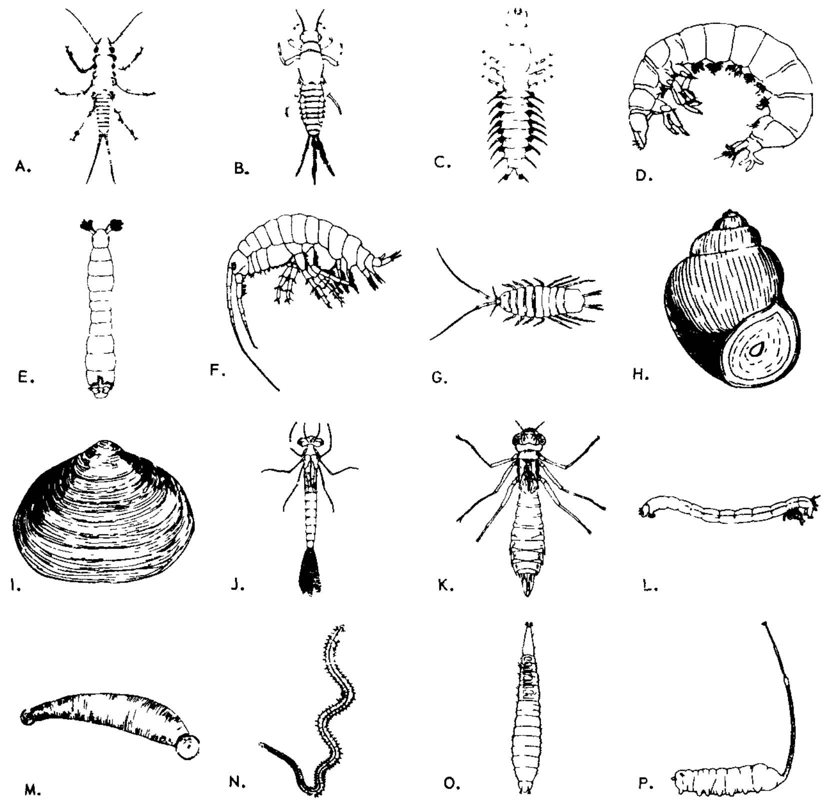
†A No. 30 U.S. Standard Sieve has openings of 0.0232 inch (0.59 millimeter) and is formed from wire 0.0114 to 0.0165 inch (0.29 to 0.42 millimeter), in diameter.



A. Stonefly nymph (Plecoptera)
B. Mayfly naiad (Ephemeroptera)
C. Hellgrammite or Dobsonfly larvae (Corydalidae)
D. Caddisfly larvae (Trichoptera)
E. Black fly larvae (Simuliidae)
F. Scud (Amphipoda)
G. Aquatic sow bug (Isopoda)
H. Snail (Gastropoda)
I. Fingernail clam (Sphaeriidae)
J. Damselfly nymph (Zygoptera)
K. Dragonfly nymph (Anisoptera)
L. Bloodworm or midge fly larvae (Tendipedidae)
M. Leech (Hirundinea)
N. Sludgeworm (Tubificidae)
O. Sewage fly larvae (Psychoda)
P. Rat-tailed maggot (Tubifera-Eristalis)

Figure 1. Representative bottom-dwelling macroanimals. (Drawings from Geckler, J., K.M. Mackenthun, and W.M. Ingram, 1963. Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control. DHEW, Public Health Service, Cincinnati, Ohio, Pub. No. 999-WP-2.)

Bottom-dwelling organisms have inherent qualities that make their use in pollution surveys advantageous: a pronounced response to pollution, a sufficiently long life cycle to prevent a response to intermittent relief from pollution, and either a means of locomotion that prohibits extended rapid migrations or a sessile-attached mode of life that reduces the influence of neighboring water conditions on the organisms. Because of these qualities, bottom-dwelling organisms reflect conditions at the sampling point for an extended period of time.

A wide variety of bottom-dwelling macroorganisms inhabit nonpolluted waters. Each occupies a niche in the benthic community, where the adaptations of the species are most efficiently utilized in maintaining life processes. Each is limited in numbers by availability of food supply, intra- and interspecies competition, predation, and the stage of its life cycle. Since all of these factors are affected by pollution, a biological survey of the bottom-dwelling macrofauna is in fact an investigation into the extent and degree of water pollution.

RESPONSES TO POLLUTION GENERALLY

SENSITIVITY

Moderate pollution reduces the number of species surviving in an area by eliminating the most sensitive ones. As the concentration of a given pollutant increases, additional species are eliminated in order of sensitivity to the pollutant until only those species that can survive the adverse conditions remain. Extreme pollution may eliminate all organisms in the area.

Elimination of the more sensitive organisms by pollution reduces competition among, and predation on, the surviving forms. The tolerant survivors increase in numbers until checked by the amount of available food and space.

TOLERANCE GROUPING

Flexibility must be maintained in the establishment of tolerance lists based on the response of organisms to the environment because of complex interrelationships among varying environmental conditions. Some general tolerance patterns can be established. Stonefly nymphs, mayfly naiads, hellgrammites, and caddisfly larvae represent a grouping that is quite sensitive to environmental changes. Black fly larvae, scuds, sowbugs, snails, fingernail clams, dragonfly nymphs, damselfly nymphs, and most kinds of midge larvae are intermediate in tolerance. Sludgeworms, some kinds of midge larvae (bloodworms), and some leeches are tolerant to comparatively heavy loads of organic pollutants. Sewage mosquitoes and rat-tailed maggots are tolerant of anaerobic environments (Figure 1).

STRUCTURAL LIMITATIONS

The morphological structure of a species limits the type of environment it may occupy. Species with complex appendages and exposed, complicated respiratory structures, such as stonefly nymphs, mayfly nymphs, and caddisfly larvae, that are subjected to a constant deluge of settleable particulate matter soon abandon the polluted area because of the constant preening required to maintain mobility or respiratory functions; otherwise, they are soon smothered. Species without complicated external structures, such as bloodworms and sludgeworms, are not so limited in adaptability. A slugdeworm, for example, car burrow in a deluge of particulate organic matter and flourish on the abundance of "manna." Morphology also determines the species that are found in riffles, on vegetation, on the bottom of pools, or in bottom deposits.

RESPONSES TO SPECIFIC TYPES OF POLLUTION

ORGANIC, INORGANIC, SLUG

Organic materials constantly undergo decomposition; if this decomposition proceeds rapidly enough to utilize all the oxygen available at the sludge-water interface, the worm's life may be in danger. Anaerobic decomposition produces methane and hydrogen sulfide. In addition to being toxic, these gases, because they are ebullient, produce an unstable substrate by stirring up the bottom and by blowing mats of sludge to the surface. Such physical action is adverse to the worms and may produce a drastic reduction in their numbers.

Wastes, such as heavy metal ions, some synthetic chemicals, and hot water, do not provide food. Thus, although they eliminate the organisms in order of increasing tolerance, they do not produce a large increase in the number of surviving forms. They also hinder or eliminate the organisms sensitive to the pollutant, and the pollutant provides no benefit to the tolerant organisms except a reduction in predation and interspecific competition.

Often the type, concentration, and quantity of waste are not uniform; any sudden or temporary change (commonly referred to as a "slug") may have a detrimental effect on a stream. Figure 2 shows the effect of duration and concentration of a "slug" on the number of kinds of bottom organisms. Two miles below the waste source (Figure 2, M-36) the duration was short, but the concentration was high, and all bottom-dwelling animals were eliminated. At M-32 six miles downstream where the duration was longer, but the concentration reduced, a lower mortality of kinds resulted. As the waste proceeded farther downstream the concentration continued to diminish; but the still longer duration resulted in an increased percentage of mortality. Figure 3 shows the effect of this waste on the dissolved oxygen concentration.

MUNICIPAL

Municipal waste contains solids originating as fecal material, garbage, household wastes, and street washings that are often disposed of through the sewerage system. Upon entering a waterway, these organic materials sink to the bottom and form sludge beds, the extent of which

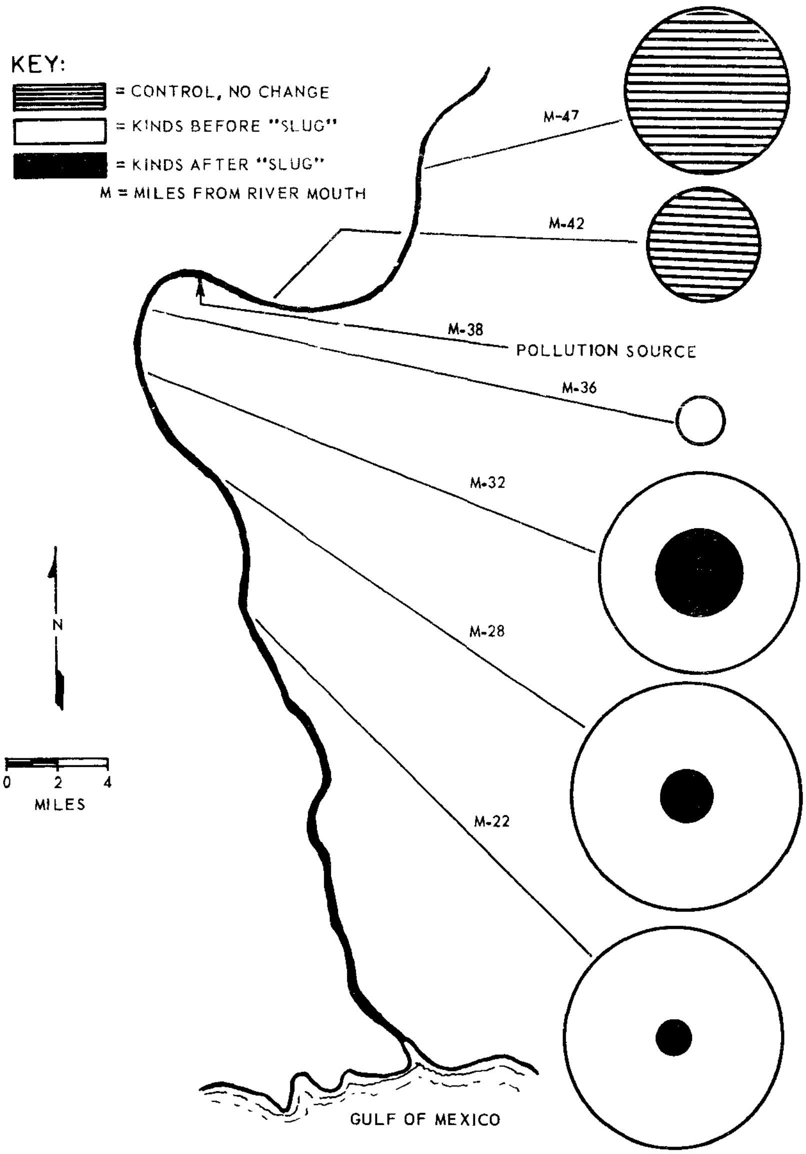


Figure 2. Comparison of effects of usual quantity of chemical wastes and slug of such wastes on number of kinds of bottom-dwelling macrofauna (East Pearl River, September 1962).

depends upon hydrological factors that govern the rate of settling and the depth of sludge deposition. A sludge bed covers the original stream bottom of gravel, rubble, and soil with a substrate or "blanket" rich in organic solids. The consequent reduction in types of niches and the physical and chemical changes associated with organic decompositior eliminate the more sensitive organisms. Figures 4 and 5 show the changes in animal populations that resulted from the addition of municipal organic wastes.

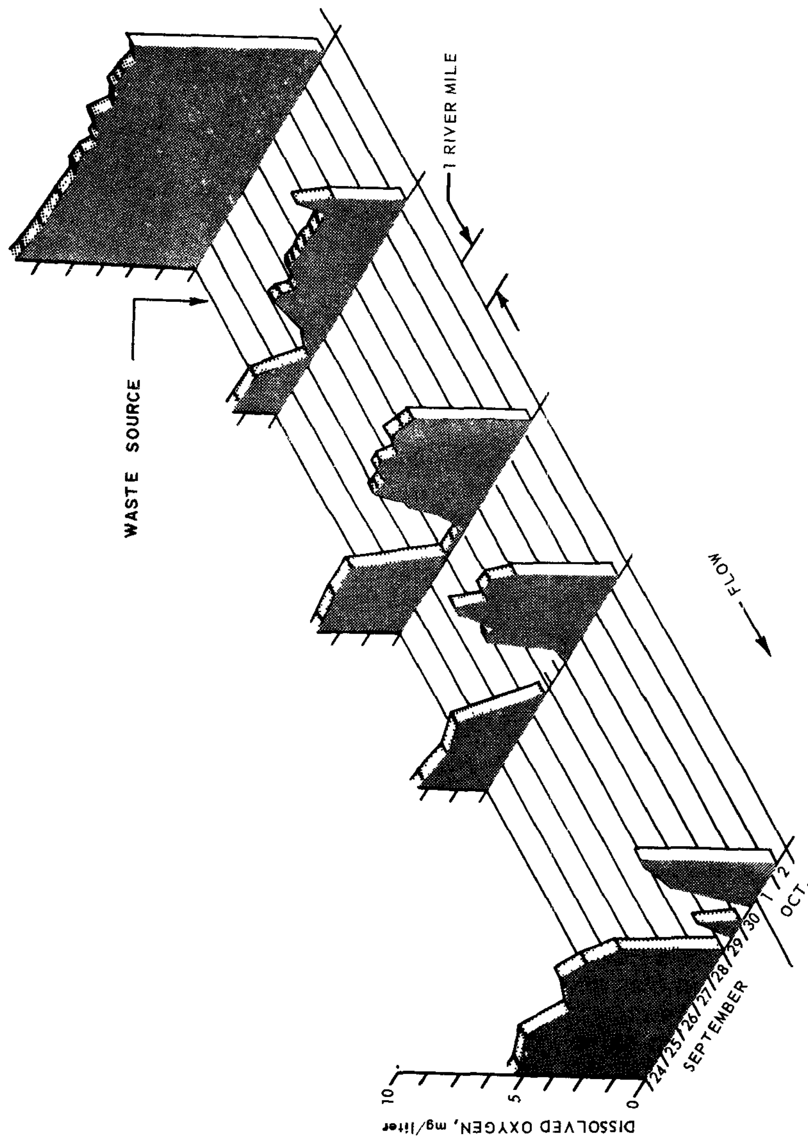
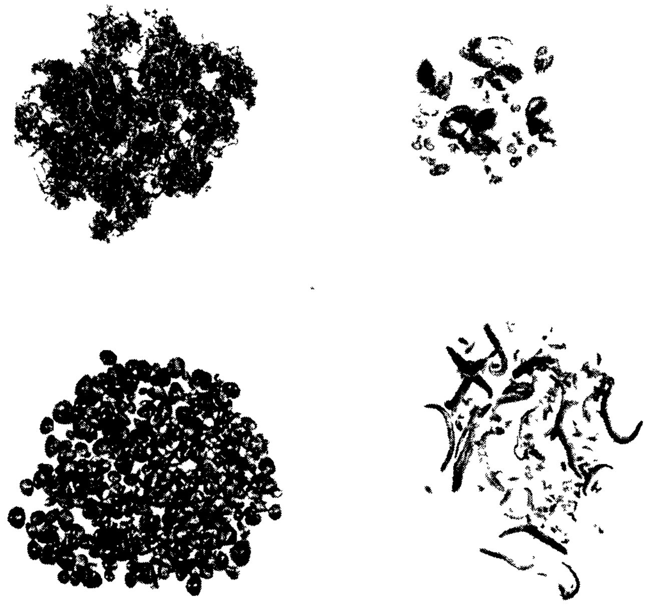
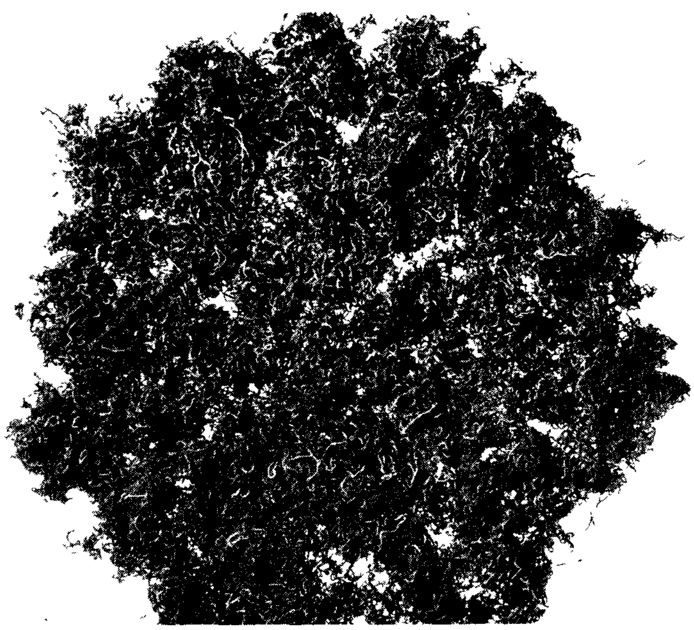


Figure 3. Drastic reduction in dissolved oxygen effected by addition of slug of waste to stream (East Pearl River, September 1962).



A. Five species survive in moderate numbers in moderate pollution.



B. Sludge worms replace more sensitive species upon addition of organic solids.

Figure 4. Effect of addition of domestic organic solids to Chicago River (April 1961).

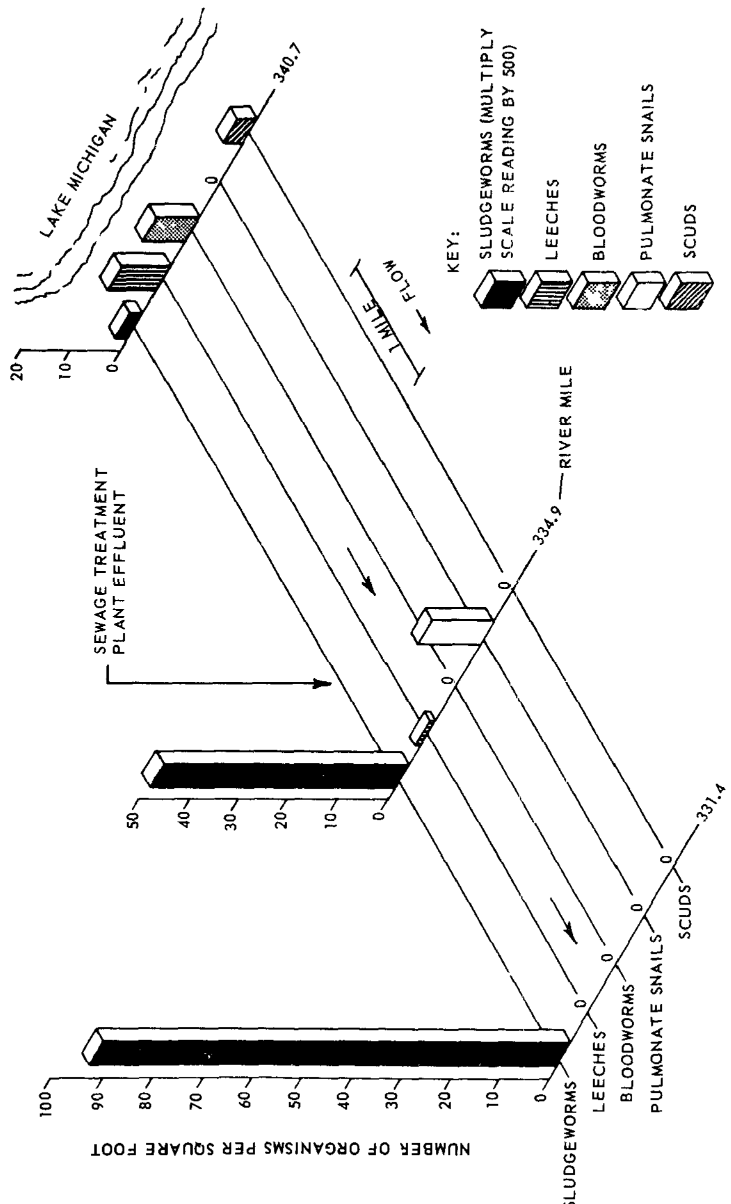


Figure 5. Effect of organic solids in North Branch of Chicago River and North Shore Canal (April 1961).

Industries that use animal or vegetable raw materials produce wastes that may degrade the environment in a manner similar to that of

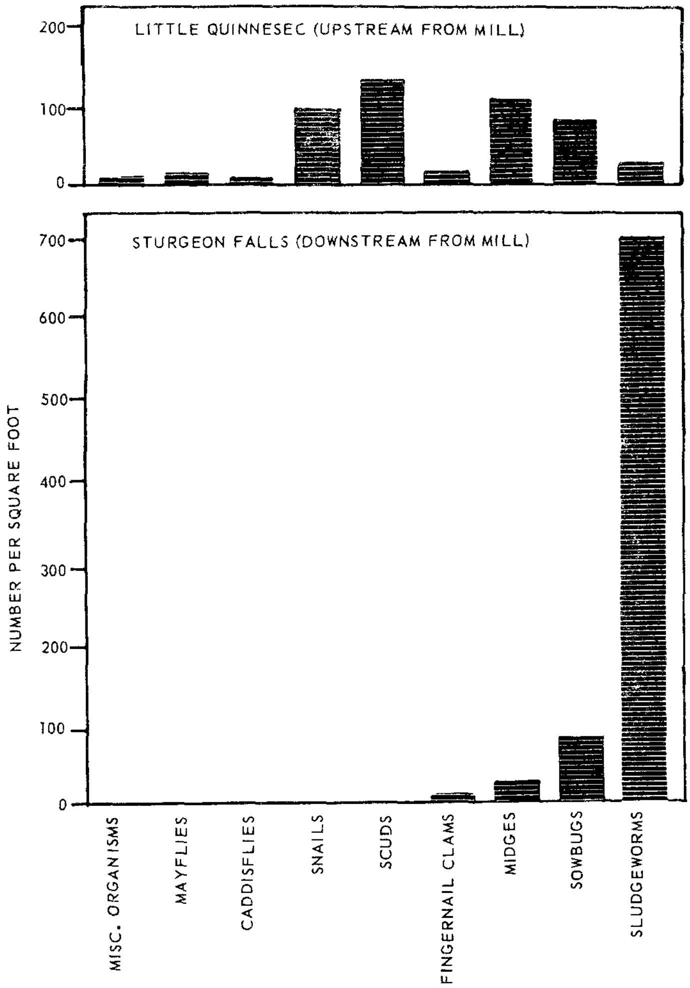


Figure 6. Effects of paper mill waste on bottom fauna. (Menominee River, August 1963).

municipal organic solids. Paper mills discharging wood fiber (Figures 6 and 7), sugar-beet mills discharging beet pulp, and slaughterhouses and rendering plants discharging animal wastes are examples of the type of pollution sources that at the same time reduce the number of species and increase the population of tolerant forms that are capable of utilizing the additional food.

Wastes from chemical plants can also reduce the number of kinds of organisms in a stream. Figure 2 shows such a reduction. The usual pollutant involved was a "uniform" quantity of wastes from the processing of crude tall oil and crude sulfate turpentine to produce chemical specialities. The exact chemical composition of the effluent is unknown. A marked decrease in number of species resulting from this waste flow was observable 2 miles downstream from the effluent. Six miles downstream, the number of species was equal to or exceeded the number upstream from the effluent.

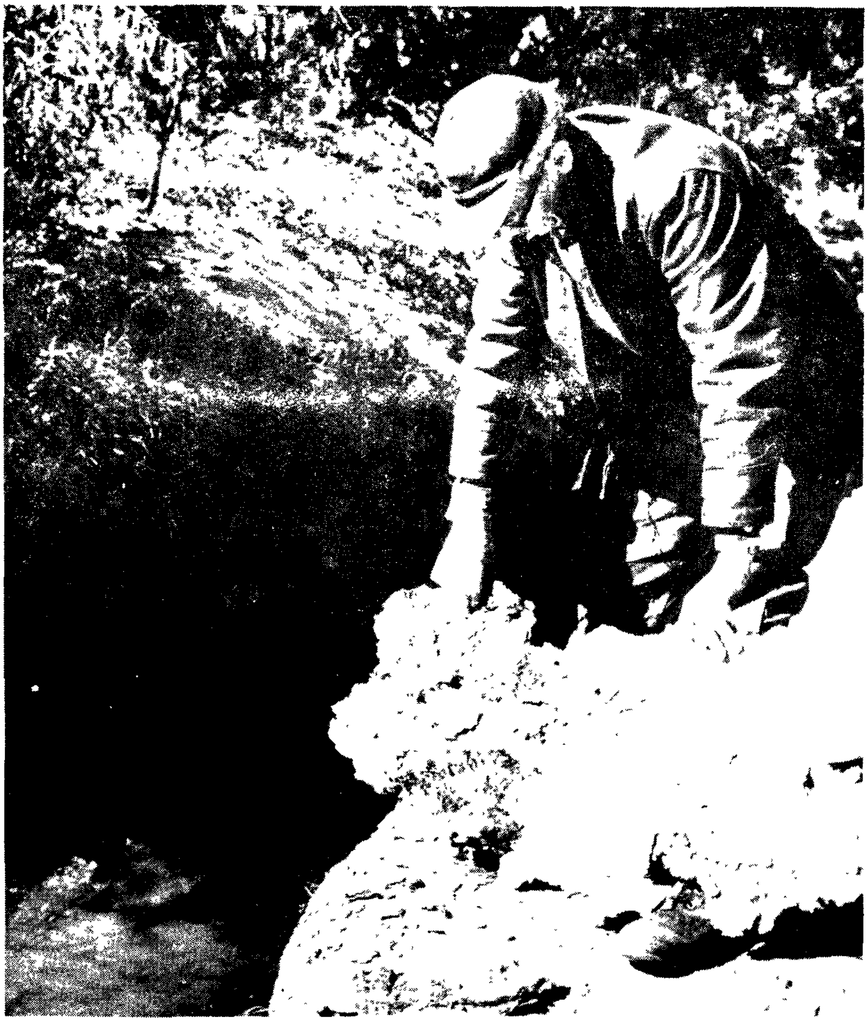


Figure 7. Heavy fibreboard formed in Connecticut River, October 1961, when discharge from paper mills dried after water levels receded.

In highly developed metropolitan areas, the pattern of stream pollution is complicated by the addition of industrial nonorganic wastes and both municipal and industrial organic solids. (See Figure 8). Samples

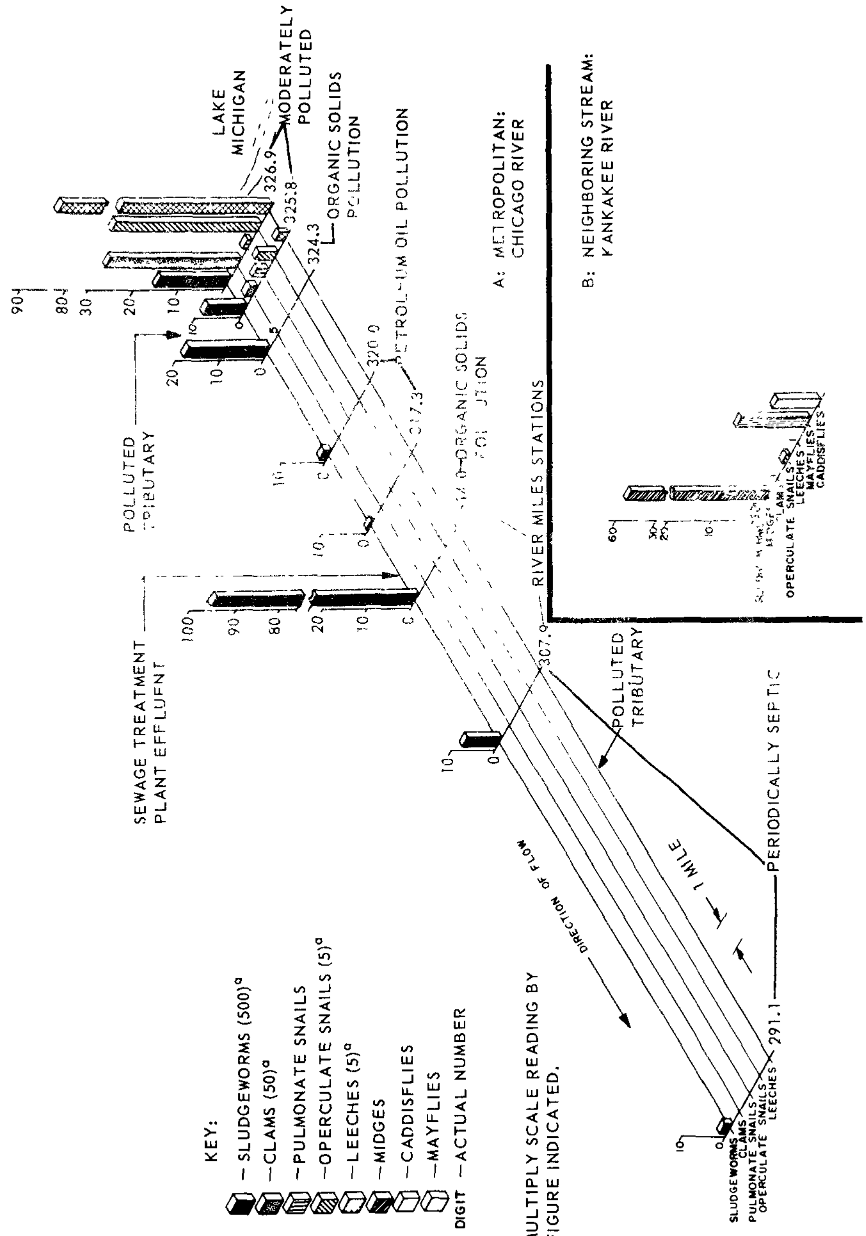


Figure 8. Effects of different types of pollution on the bottom fauna of two waterways (April 1961).

from the Chicago River (miles 326.9 and 325.8) had a diverse fauna in contrast to the downstream stations. This fauna is still not indicative of water as clean as that found in a neighboring stream. Just above mile 324.3, a stream enters that is enriched with organic solids that settle and form sludge that eliminates the more sensitive species and feeds a larger population of sludgeworms. At the next two downstream stations, a reduction in organic solids and the accumulation of comparatively large quantities of petroleum oils in the bottom substrate reduce surviving tolerant sludgeworms. The addition of a relatively large volume of domestic sewage effluent then dilutes the effects of these oils and feeds a large population of sludgeworms at station 314.0. Farther downstream, the stream periodically becomes septic with a resulting reduction in numbers of sludgeworms at stations 307.9 and 291.1.

NATURAL (SILT)

Silt and other inert solids are also pollutants. Figure 9 shows the amount of silt that can be carried by water. Inert silt provides no food and may smother or grind up more sensitive organisms. Figure 10 shows the destructive effect of silt on the number of kinds of animals: a general downstream reduction. The scouring and smothering effects were so severe in this river that only one animal form was found at the last downstream station.

Figure 9. Settled water samples from Virgin River showing varying quantity of silt found in suspension (August 1961).

DATA COLLECTION AND INTERPRETATION

The field sample collection is the basic element of a survey, and it should be representative of the total environment.

SAMPLING

Qualitative sampling determines the variety of species from an area. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but they generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced from 100 to 1 per square foot, whereas sludgeworms may increase from 1 to 14,000 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms.

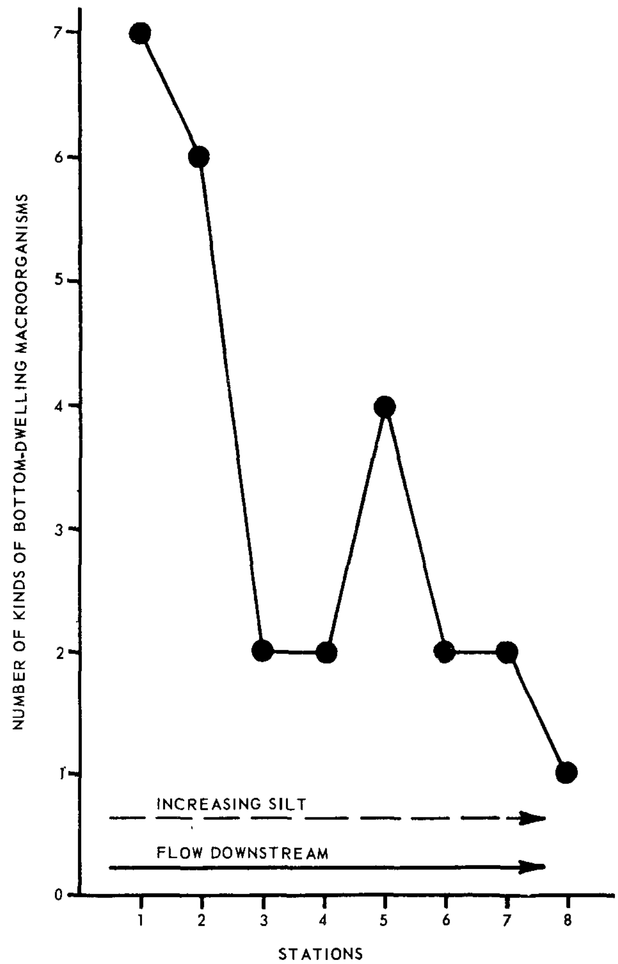


Figure 10. Effect of silt on number of kinds of bottom-dwelling macrofauna (Virgin River, August 1961).

Quantative sampling is performed to observe changes in predominance. The most common quantitative sampling tools are the Petersen and Ekman dredges and the Surber stream bottom or square-foot sampler (Figure 11). Of these, the Petersen dredge samples the widest variety of substrates. The Ekman dredge is limited to fine-textured and soft substrates, such as silt and sludge. The Surber sampler is designed for sampling riffle areas; it requires moving water to transport the dislodged organisms into its net and is limited to depths of 2 feet or less.

The collected sample is screened with a standard sieve to concentrate the organisms; these are sorted from the retained material, and the number of each species is determined. Data are then adjusted to number per unit area, usually to the number per square foot of bottom or occasionally to number per square meter. This adjustment standardizes the method of data expression.

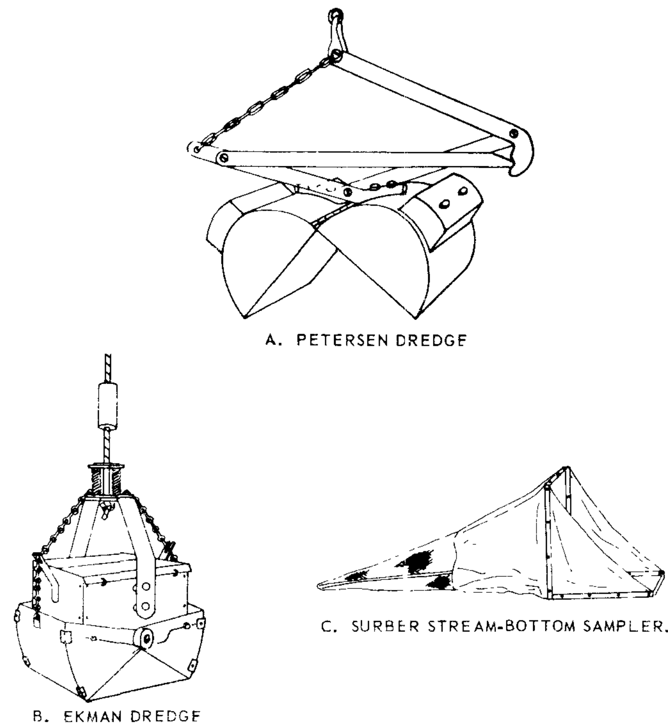


Figure 11. Tools for collecting quantitative samples of bottom-dwelling macrofauna. (Drawings from Geckler, J., K.M. Mackenthun, and W.M. Ingram, 1963. Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control. Dept. HEW, Public Health Service, Cincinnati, Ohio, Pub. No. 999-WP 2.)

Independently, neither qualitative nor quantitative data suffice for thorough analyses of environmental conditions. A cursory examination to detect damage may be made with either method, but a combination of the two gives a more precise determination. If a choice must be made, quantitative sampling would be best because it incorporates a partial qualitative sample.

EXTRAPOLATION

How can bottom-dwelling macrofauna data be extrapolated to other environmental components? It must be borne in mind that a component of the total environment is being sampled. If the sampled component exhibits changes, then so must the other interdependent components of the environment. For example, a clean stream with a wide variety of desirable bottom organisms would be expected to have a wide variety of desirable fishes; if pollution reduces the number of bottom organisms, a comparable reduction would be expected in the number of fishes. Moreover, it would be logical to conclude that any factor that eliminates all bottom organisms would probably eliminate many other aquatic forms of life.

Even though biologists often speak of "pollution indicator" macrobenthic organisms, the presence of these organisms is not a true indication of pollution. Most so-called "indicators" were present in the natural environment long before man began to dump his wastes into the world's waterways. Evolution has not produced species specifically adapted to live in "sewers." The sludgeworm evolved and subsisted in areas (such as an eddy behind a rock) where natural organics accumulated long before man created a habitat where sludgeworms could flourish over many acres. The extent and degree of pollution are better indicated by the absence or reduced number of organisms associated with clean water.

FACTORS INVOLVED IN DATA INTERPRETATION

Two very important factors in data evaluation are a thorough knowledge of the conditions under which the data were collected and a critical assessment of the reliability of the data's representation of the situation. For example, in Figures 9 and 10 one interpretation of the data could be that relatively poor watershed utilization by agriculture and forestry causes the situation illustrated. This material is, however, from a stream that flows through arid desert country; record flash floods sweeping down barren desert arroyos had "degraded" this stream with silt and sand.

MINIMUM-MAXIMUM VALUES

The evaluation of physical and chemical data to determine their effects on aquatic organisms is primarily dependent on maximum and minimum observed values. The mean is useful only when the data are relatively uniform. Figure 3 shows data that, if averaged, would indicate that enough dissolved oxygen was present to support a desirable fauna, but in fact, the short-term dissolved oxygen minimum would suffocate those organisms that were not able to "hold their breath" for the duration of its absence. The minimum or maximum values usually create the acute conditions in the environment.

FOOD SUPPLY

A moderate quantity of microscopic food particles in the water can produce large populations of black flies, biting midges, nonbiting midges, and mosquitoes. The amount of food required is that which will permit a delicate adjustment in the biota. Enough organic food must be added to suppress the more sensitive predators and competitors, but the quantity and quality of waste cannot be such that they suppress moderately tolerant forms.

IDENTIFICATION

Precise identification of organisms to species requires a specialist in limited taxonomic groups. Many of the immature aquatic forms have not been associated with the adult species. Therefore, one who is certain of the genus but not the species should utilize the generic name, not a potentially incorrect species name. The method of interpreting biological data on the basis of numbers of kinds and numbers of organisms will typically suffice. For example, Figures 2, 5, and 10 are based on identifications to genera, family, and suborder respectively.

LAKE AND STREAM INFLUENCE

Physical characteristics of a body of water also affect animal populations. Lakes or impounded bodies of water support different faunal associations than do rivers. Major taxonomic groups of organisms are present in both, but there is generally a change in species composition. The number of kinds present in a lake may be less than that found in a stream because of a more uniform habitat. A lake is all pool, but a river is composed of both pools and riffles. The nonflowing water of a lake exhibits a more complete settling of particulate organic matter that naturally supports a higher population of detritus consumers. For these reasons, the bottom fauna of a lake or impoundment cannot be directly compared with that of a flowing stream.

Nor can the fauna of a tributary rivulet be directly compared with that found in its much larger receiving stream. As streams become larger and the flow slower, their physical characteristics become more uniform and approach those of a lake. This is especially evident where the water's velocity has been further reduced by the addition of dams and locks for navigation. Therefore, the smaller streams may contain more species than larger receiving streams.

CONCLUSION

The final step in treating a pollution problem, providing an answer, involves persuading the polluter to eliminate or control the cause of pollution. If persuasion is not successful, then findings must be presented to the public and the alleged polluter at a conference, hearing, or, if necessary, in formal litigation. In this confrontation the data accumulated from the study of bottom-dwelling macrofauna as to degree and extent of water pollution may prove determinative of the issue.

ACKNOWLEDGMENT

The theory and application of bottom-dwelling macrofauna analyses as a useful tool in pollution prevention and abatement have evolved from the work of innumerable people. Their ideas have been transmitted both orally and in the literature; no one individual or group is solely responsible for any concept outlined in this paper. For this reason, no literature has been cited. The bibliography that follows will enable pollution analysts to obtain information on the ecology of waters that is pertinent to the protection of aquatic organisms.

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