WATER POLLUTION MICROBIOLOGY

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Edited by

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Preface

An increasing number of courses are taught both in biology departments and in engineering schools which attempt to assess the role of microorganisms in water pollution and their control. Too often these courses use out-of-date information and concepts. However, it is quite difficult to provide current information and ideas about two such apparently divergent fields as microbiology and water pollution. The objective of this book is to provide a text for advanced courses in which modern microbiological concepts are applied to the solution of problems in water pollution control. For my own teaching I have relied on original publications to bridge the gap between the microbiologist and the engineer. I attempted in my selection of contributors to this volume to provide the reader with both the information available in those original articles and a critical assessment of that information by the person most competent in that field.

Obviously it was not possible to be comprehensive. I would have liked to include chapters on general ecological principles, energy transfer, and many other topics. However, the economic limitations dictated that only the most pertinent subjects be included.

I hope that this volume will stimulate the student to initiate research into the microbiology of both polluted and unpolluted waters. Only by obtaining a clear understanding of the fundamental nature of aquatic ecosystems and the effect of perturbations on them can we hope to develop new concepts which will ultimately yield effective and economic pollution control.

I express thanks to the Environmental Protection Agency for their support in the preparation of this book.

The editor wishes to thank the Macmillan Company for permission to quote from *The Collected Poems of W. B. Yeats.*

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Cambridge, Massachusetts
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1 Sources of Water Pollution

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1-1. Introduction

Pollution is defined by Cairns and Lanza in Chapter 10 of this volume as the appearance of some environmental quality for which the exposed community has inadequate information and is thus incapable of an appropriate response. In healthy waters, the level of pollution is sufficiently low that the native microbial community contains the information necessary to neutralize the negative effects. The ability to reverse the effects of pollution or to maintain natural waters in a healthy state is dependent on the capacity to understand the ecological processes responsible for the transfer of this information. Our knowledge of these processes is meager indeed.

The relationship between microbiology and pollution control of many of the subjects discussed in this book is self-evident. However, some sources of pollution whose origin has been recognized more recently, including eutrophication, thermal pollution, and oil pollution, require some introduction and will be discussed below.

1-2. Pollutants

The term eutrophication is derived from the Greek *eutrophos,* which means "corpulant." Eutrophic waters have been enriched with nutrients which support excessive algal photosynthesis. The microbial degradation of these algae results in oxygen depletion of natural waters. Secondary effects include extensive fish kills, decline in recreational value, and foul taste in drinking water.

Lake Erie provides a classic example of accelerated eutrophication (1). The total concentration of phosphorus in the lake doubled between 1942 and 1958. The dissolved oxygen concentration in 1959 was less than 3 ppm in 75% of the lake bottom.

At that time the fish population had completely changed. Blue pike, which were among the dominant fish prior to 1950, began to decline in the late 1950s and had completely disappeared by the mid-1960s. The white fish and walleye population collapsed at the same time. Commercial production of these fish was approximately 10 million pounds per year for each fish prior to the mid-1950s. By 1965 less desirable fish began to predominate and commercial production had declined dramatically. The data shown in Figure 1.1 are typical of highly eutrophic situations. Similar conditions can be found in impounded waters in most countries of the developed world (2).

Municipal and agricultural wastes account for most of the nutrients entering natural waters. Less than 30% of the population of the United States is served by sewage treatment plants. Most plants in use depend on secondary treatment which removes much of the available organic matter, but only 30% of the phosporus and 20% of the nitrogen. Thus the conventional sewage treatment plant releases high concentrations of nutrients into surface waters. The remaining phosphorus and nitrogen must be removed by tertiary treatment if eutrophication is to be reversed.

Animal wastes and fertilizers are an important source of eutrophication in agricultural areas. The animal population in the United States in 1970 was estimated at 564 million head with a waste level equivalent to 2 billion people. In areas where animals are concentrated, the potential eutrophication is enormous. Similarly, in areas of intense crop production the sharp rise in the use of fertilizers in the past decade has dramatically increased the rate of eutrophication of local waters.

The role of phosporus in eutrophication is discussed by Stumm and Stumm-Zollinger in Chapter 2, and the role of nitrogen is discussed by Goering in Chapter 3.

More than 10,000 miles of streams in the United States are contaminated by acid drainage from abandoned coal mines. The passage of water through the mines is accompanied by microbiological action in which pyrites are oxidized to yield sulfuric acid. The pH usually declines to 4 or lower, and there are no fish living in these waters. However, dense mats of algae develop. Acid mine water cannot be used for drinking by humans or livestock without treatment.

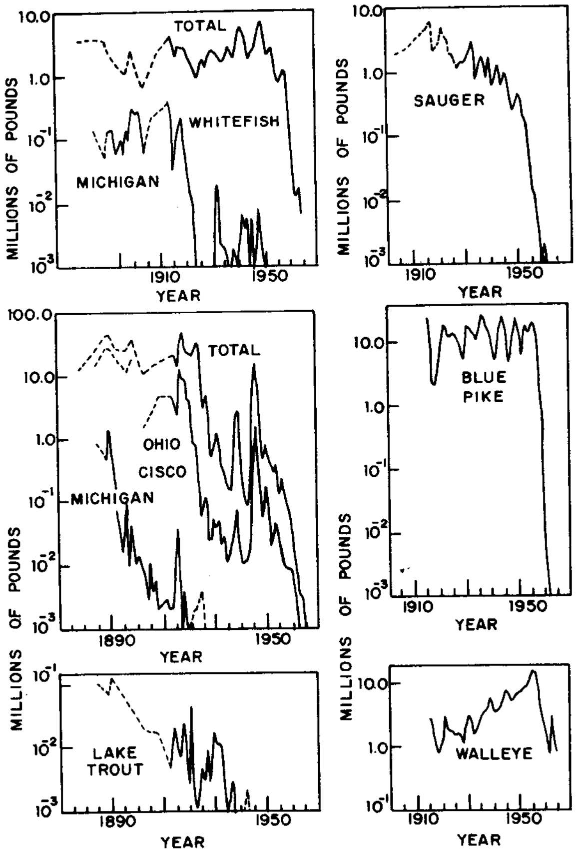

Figure 1.1 Commercial production of blue pike, cisco (lake herring), lake trout, sauger, walleye, and whitefish in Lake Erie. Broken lines represent production during periods when annual data were not available (1).

It would be desirable to treat either the source waters or the mine itself to prevent the development of acidity. However, our knowledge of the processes occurring in the mine is insufficient for the development of adequate control measures. Neutralization by lime is widely practiced. Prevention of oxidation by sealing mines has been attempted without significant success. More information about the biochemistry and ecology of the microorganisms responsible for acid production in mines undoubtedly would lead to the development of adequate control measures.

The microbial processes controlling the production of acid mine wastes are discussed by Lundgren, Vestal, and Tabita in Chapter 4.

We have only recently begun to realize that vast quantities of oil find their way into the sea, accumulate there, and cause extensive damage to the biota. The most obvious result of oil pollution is the death of large numbers of birds and fish. However, the most destructive effects occur in the intertidal zones and are not immediately obvious to the untrained observer. These are the zones of intense biological activity where invertebrates breed and where there are high concentrations of algae. When hydrocarbons settle on these sediments, they kill both invertebrate larvae and algae. Processes controlling degradation of hydrocarbons in the sea are discussed by Floodgate in Chapter 7.

The disturbance of biological communities is a potential danger of oil pollution. Many aquatic organisms use chemical signals to communicate with each other. These signals are essential for reproduction, aggregation, and detection of prey by predators. The male lobster, for example, is attracted to the female by a chemical exuded by the female. The gravid female exudes another chemical which repels the male. The ability of starfish to find their prey, the oyster, is facilitated by exudation of a chemical by the oyster which the starfish can detect. The chemical detection of prey by predators is not confined to animals in the aquatic environment. Microbial predators can also chemically detect their prey. These microbial predator–prey detection systems are totally inhibited by crude oil and by hydrocarbons. Blumer (3) demonstrated inhibition of the starfish–oyster predation by crude oil. The implications of this form of inhibition for marine ecology are obvious.

The hazards to man from hydrocarbons in oil lie in their concentration in the food chain. One would expect to find a situation analogous to DDT, that is, apparently innocuous concentrations of hydrocarbons in the water concentrating to hundreds or thousands of ppm in fish. Many of the aromatic hydrocarbons which are extremely slow to degrade probably find their way into the food chain in this way. The fact that many of these compounds are carcinogenic should make determination of accumulations in marine fish a priority for research. Kaufman and Plimmer describe the hazards to man of pesticide hydrocarbons in Chapter 8.

The use of electricity in the United States is increasing at a rate of approximately 7% per annum. Power plants usually depend on surface water as coolants. The development of nuclear sources of power, which require approximately 50% more water for each temperature rise than fossil fuel plants, will markedly increase the quantity of surface water required for cooling purposes in the next few years. A projection of that development is shown in Figure 1.2. It has been estimated that if the trend in power use continues, the power industry will be using more than 20% of the fresh runoff water by 1980 (4).

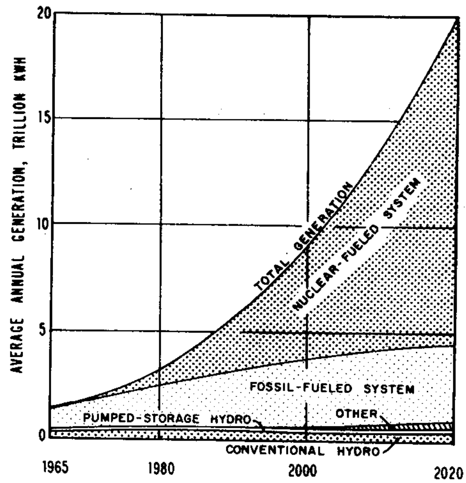

Figure 1.2 Projected development of sources of electrical power in the United States (4).

The effects of increased temperature on the aquatic environment are striking. Higher temperatures serve to de-aerate the water. Thus the river might have a strong capacity to assimilate organic matter at the ambiant temperature of 23°C. If waste heat increased the temperature to 30°C, the dissolved oxygen concentration would fall below the minimum required to satisfy existing stream standards (4). In impounded waters an input of heat would cause destratification with the consequent upwelling of nutrients, and a further decline in water quality. In Chapter 10 Cairns and Lanza describe the detrimental effects of thermal pollution on algal and protozoan communities.

For almost a century water pollution control has been based on two principles: (*a*) infinite dilution of the wastes and (*b*) secondary treatment. In areas of low population density it has also been assumed that both organic matter and pathogens would be diluted in the infinite sink of the biosphere. In recent years urbanization has forced the development of facilities for domestic wastes where local outfalls were acceptable in earlier times. The quantities of domestic waste flowing into rivers, lakes, and the sea were simply too great for the natural waters to be considered an infinite sink. The negative effects of eutrophication are not sufficiently realized in many areas. Secondary treatment facilities are being built to overcome the problem of the infinite sink. However, this form of treatment, while disposing of the organic matter and pathogens in the sewage, allows high concentrations of nutrients to be returned to the natural water.

The fallacy inherent in the consideration of our natural waters as an infinite sink is most apparent when we deal with industrial wastes, pesticides, oil, and waste heat. We are only beginning to understand that chemicals may accumulate in the biosphere and cause widespread, deleterious ecological changes. Our rapidly increasing use of power could result in a change in the biological equilibrium in many of our rivers and lakes.

H. T. Odum, in his monograph on the relationship between the environment, power, and society (5), points out that industrial man has upset the equilibrium of the biosphere by utilization of fossil fuels. This puts a great stress on the biosphere as the absorbent of wastes with low levels of energy. The resultant perturbations adversely affect both energy and material flow through the system. Table 1.1 shows Odum's view of the effect of stress

Table 1.1 Species Diversity in Some Systems (5)

System	No. of Species Found When 1000 Individuals Are Counted
Systems with few species in stressed environments	
Mississippi Delta, low salinity zone	1
Brines	6
Hot springs	1
Polluted harbor, Corpus Christi, Texas	2
Complex systems in stable environments	
Stable stream, Silver Springs, Florida	35
Rain forest, El Verde, Puerto Rico	75
Ocean bottom	75
Tropical sea	90

on the diversity of species in natural populations. It is apparent from this table that in the absence of perturbations homeostasis is maintained in biological systems, and there is a maximal level of diversity. Under conditions of stress, diversity declines and the whole ecosystem becomes more unstable. A more detailed discussion of H. T. Odum's approach to disturbances of energy flow by auxiliary energy sources is discussed by Stumm and Stumm-Zollinger in Chapter 2.

The one statement that can be made with certainty about these ecological disturbances is that we are only beginning to diagnose pollutants which either accumulate in the food chain or have a deleterious effect on the biota in extremely low concentrations. We are virtually ignorant of the ecological processes and interrelationships occurring in either healthy or polluted natural waters.

Our capacity to restore the quality of our natural waters is not simply dependent on legislation or on current technology on waste treatment.

Water pollution is analogous to a newly discovered group of diseases. Before these diseases can be adequately controlled, we must study extensively the nutrition and physiology of the patient.

Information gained from these studies will enable us to determine which materials disturb the ecology of natural waters or are potentially hazardous to man. Hopefully we can develop new concepts which we can use to prevent these materials from entering our natural waters. An understanding of the process of self-purification of natural waters may facilitate the development of new standards for materials which are already accepted as pollutants, but whose effect either on the environment or on man is as yet largely unknown. This information may also lead to the development of processes by which pollutants already in a natural water, for example, nutrients or oil, can be neutralized.

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Part I

Microbial Changes Induced by Inorganic Pollutants

2 The Role of Phosphorus in Eutrophication

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One of the most important problems in the pollution of inland waters is the progressive enrichment of waters with nutrients concomitant with mass production of algae, increased water productivity, and other undesirable