EFFECTS OF ENVIRONMENTAL POLLUTION ON ECOLOGICAL SYSTEMS

by C. H. Ward

Recently, Dr. H. B. N. Hynes, a noted ecologist, said in a symposium address that, " . . . although pollution is damaging our environment in many ways, we know how this is happening and in most respects we know how to stop it. Technologically most of the problems are solved. . . . The rest is largely a matter of finance, administration and education . . . it is now largely a matter of seeing to it that our politicians and administrators organize [meaning pollution control] that it is done properly" (Hynes, 1965).

In making the above statements, Dr. Hynes refers to conditions as they exist in Great Britain. However, a similar philosophy appears to be prevalent in the United States. That is, if given enough money and legislative control, pollution surveys and applications of present technology could eliminate the pollution problem. I am sure this approach is needed and will provide significant initial relief. But it will not provide adequate information on which to base realistic pollution standards or provide the knowledge requisite to understanding the biological effects of pollution. Pollution problems will not disappear following a crash cleanup program.

The Assistant Secretary of the Interior for Fish and Wildlife and Parks, Stanley A. Cain, believes that " . . . much more attention must be given to ecological research if the total public interest is to be served . . . and . . . the quality of the environment is to be maintained and restored" (Cain, 1967). What does Mr. Cain mean by ecological research? Ecology is the science that deals with the interrelationships between organisms (including man) and their environment. We all have a working, but highly imperfect, knowledge of how man interacts with his fellow man and in turn with the environment.

Today we are addressing ourselves to the role of man as spoiler of his environment. Plants and animals also interact with one another and their environment. In the process they, too, pollute their environment. It should

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be recognized that nature pollutes nature and that man's activity is just another link in the process, albeit an increasingly important one. Pollution exerts little biological influence except in areas of population stress. Nature normally minimizes pollution effects by dilution. But, as population and pollution concentrations increase, the ratio of diluent (water or air) to pollutant decreases and biological imbalances become manifest.

At this time we are experiencing a state of great public awareness of pollution problems. People are becoming more concerned with the quality of their environment. Water resources need to be developed. Air and water pollution abatement is greatly needed and the public has never been more aware of the need for nature conservation. Unfortunately, we do not have the background of ecological research to support and provide guidance for these worthwhile human endeavors. Classically, the ecologists have sought to understand the workings of biological populations and communities using techniques of gross measurement and correlation. The ecosystems of choice have been those relatively undisturbed by human activity. However, man's activities today are predominant among biotic influences affecting the earth's ecology. Hence, we must investigate these man-made effects to insure that planned improvements do not unduly alter our natural surroundings. Ecology is no longer a descriptive science. Analytical tools are available to support a truly experimental approach to the study of natural systems. Ecosystems such as those of streams and forests can be subjected to detailed chemical, physical, biological, and mathematical analysis. A much greater understanding of the mechanisms operating in the control of natural systems must be obtained before a long-range, realistic approach to environmental engineering and pollution can be formulated.

It is true that control mechanisms operating in natural systems are highly complex and strongly resistant to experimental field analysis. The constantly changing environment in natural systems serves to confound results due to lack of repeatable observations. Interactions between biota are so numerous that frequently only gross physiological measurements are possible. Interpretations and formulations of principles are severely limited. However, our long-range goals for a better environment dictate that we unravel, discover, and understand the principles that control our ecology.

Associations that appear too complicated for analysis in natural systems can be dissected, simplified, and elucidated to some extent in the laboratory. Some knowledgeable people believe that laboratory studies on ecosystems or on the effects of pollution are of little value because results obtained often are not directly applicable to natural systems. However, I would like to use a recent study to illustrate the value of laboratory experimentation in discovering the underlying principles operating in natural systems.

Lakes and streams contain a diverse biota including bacteria, algae, higher plants, and numerous animal forms. Pollution by foreign substances can be detrimental or beneficial depending on the species in question. Excessive pollution by organic materials promotes bacterial growth to the point that oxygen is depleted and fish and other animal life are adversely affected. Heavily polluted streams may become anaerobic and foul smelling because of bacterial action. The growth of algae tends to counteract oxygen depletion by bacteria; oxygen is a biproduct of photosynthesis. Most of the oxygen liberated by aquatic photoautotrophs is dissolved in the surrounding medium and is available to other organisms, including fish.

We wanted to gain a better understanding of the principles that govern the relationships between bacteria and algae and to determine the effects of bacteria on photosynthetic productivity. Investigations of this nature can be conducted only with great difficulty, if at all, in the field. Measurements on natural systems would be complicated by other variables to the extent that basic mechanisms probably would be obscured.

We chose to study pure cultures of algae and bacteria growing under precisely controlled conditions of temperature, nutrient, light, pH, and gaseous environment. Isolations of bacteria from algal cultures revealed that a highly select bacterial flora is associated with algae in the absence of pollution, indicating that pollution *per se* probably enhances bacterial diversity. We found that bacterial growth is not dependent on exogenous organic pollution, but is dependent on and strongly correlated with algal growth (Figure 1). The pattern and magnitude of growth of bacteria

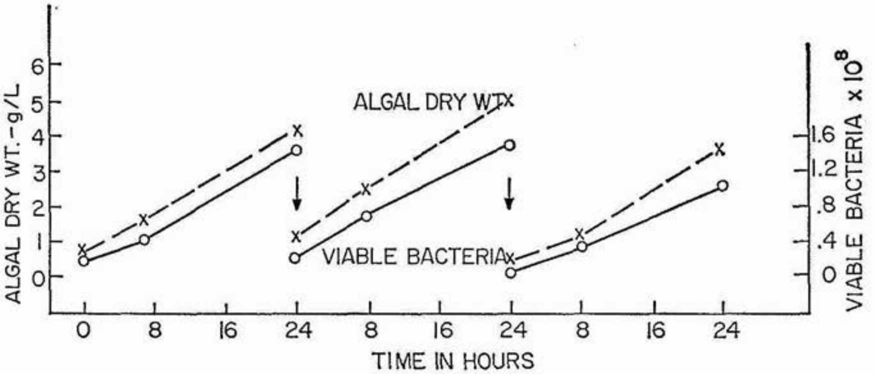

FIGURE 1 - GROWTH OF CHLORELLA PYRENOIDOSA TX71105 AND SELECTED BACTERIA IN MASS CULTURE (WARD et al 1964)

when present as single species in algal cultures were species dependent

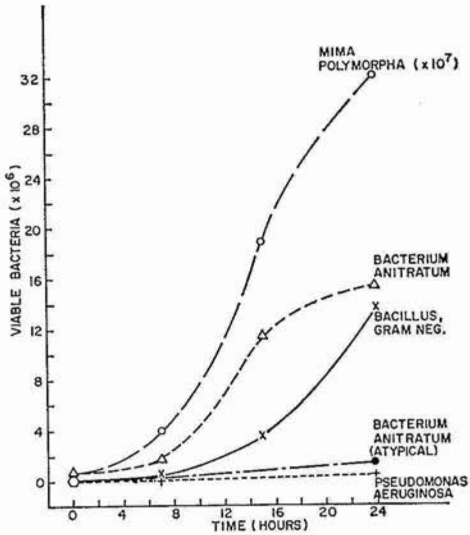

FIGURE 2 - GROWTH OF BACTERIA IN ALGAL CULTURES (WARD et al. 1964)

(Figure 2). In algal cultures containing more than one bacterial species, growth patterns also differed due to competition (Figure 3). Certain

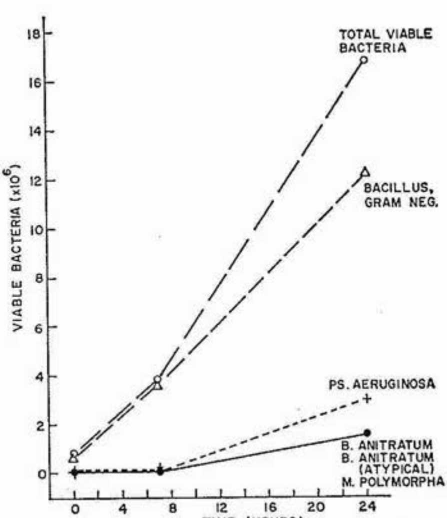

FIGURE 3 - CONCURRENT GROWTH OF FIVE BACTERIA IN A CULTURE OF CHLORELLA PYRENOIDOSA TX 71105 (WARD et al, (1964)

bacterial forms were found to adversely affect the growth of algae (Table 1). Four of six bacteria tested decreased algal growth from 5 to 13 per cent; however, the effects were not additive because the combined effect of the bacteria was no greater than that of each bacterium acting independently.

TABLE 1.
Effects on bacteria on the growth of *Chlorella pyrenoidosa* TX71105, bacterial growth in algal cultures, and bacterial contribution to culture mass
(Ward et al., 1964)

Bacterium	Algal growth with bacteria[a]			Viable bacteria	
	O.D.	Cell No.	Dry Wt.[b]	No. X10^6/ml	%Dry Wt.
Mima polymorpha	104	80	95	311.3	1.03
Bacillus, gram neg.	—	80	91	13.6	0.71
Bacterium anitratum	89	77	87	14.5	0.98
Bacterium anitratum (atypical strain)	98	100	102	1.2	0.56
Pseudomonas aeruginosa	101	80	89	0.4	0.01
Aerobacter cloacae	103	101	103	22.2	0.25
Combined bacteria[c]	91	85	88	16.1	0.93

Data are means of six or more replicates corrected for initials and
[a]expressed as per cent of bacteria-free controls,
[b]corrected for contribution of bacteria,
[c]first five bacteria listed.

We also found that heterotrophic bacteria are capable of excellent growth on inorganic algal medium after the algae have been removed (Figure 4),

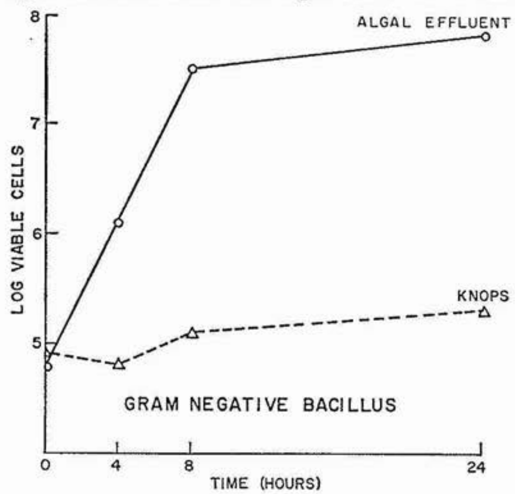

FIGURE 4 - GROWTH OF A GRAM NEGATIVE BACILLUS IN EFFLUENT KNOP'S SOLUTION FROM 24 - HOUR AXENIC CHLORELLA PYRENOIDOSA TX 71105 CULTURES (WARD et al,1964)

probably negating any obligate parasitic or pathogenic mechanism. It would appear then that algae support a select bacterial flora by excreting organic bacterial nutrients and that metabolite excretion is not an induced response caused by the presence of bacteria.

Organic compounds present in axenic algal culture filtrates were separated and identified (Table 2). A variety of organic acids and amino acids

TABLE 2.

Extracellular products of *Chlorella pyrenoidosa* TX71105 present in axenic culture filtrates (Ward and Moyer, 1966)

Organic acids	Amino acids	Other
Fumaric	Aspartic	Polysaccharides
Lactic	Glutamic	Short peptides
Glycolic	Serine	Nucleic acids
Oxalic	Threonine	Ammonia
Pyruvic	Isoleucine	
α-ketoglutaric	Leucine	
Oxalacetic	Tyrosine	
Ascorbic	Phenylalanine	
Gluconic	Lysine	
Galacturonic	Proline	
	Alanine	
	Glycine	
	Cystine	
	Valine	
	Histidine	
	Ornithine	

were found that are known to serve as sources of carbon and energy for bacterial growth. Utilization of algal excretory products was studied using four bacteria growing singly and in combination in axenic culture filtrates

(Table 3). We found that each bacterium had a different pattern of ex-

TABLE 3.

Utilization of excretory products of *Chlorella pyrenoidosa* TX71105 by selected bacteria (Ward and Moyer, 1966)

Compound	conc. in algal filtrate μg/ml	Relative Utilization[a] BAT	BAA	MP	GNB	Combined
Aspartic acid	13.3	†††	†††	†	†††	†††
Threonine	4.8	†††	†††	††	†††	††
Serine	5.3	†††	†††	††	†††	†††
Glutamic acid	11.8	†	†	††	—[b]	†††
Proline	3.7	†††	†††	†††	††	†††
Alanine	5.3	†††	†††	††	†††	†††
Isoleucine	2.1	†††	†††	††	—	†††
Leucine	1.9	†††	†††	†††	—	†††
Tyrosine	trace	†††	†††	—	—	†††
Phenylalanine	1.2	†††	†††	†††	††	††
Lysine	trace	—	—	—	†††	†††
Lactic acid	1.1	—	†††	—	†††	†††
Glycolic acid	1.3	—	†	—	—[b]	†

[a]Data are relative: †††, indicates complete removal; ††, trace remaining; †, one half or more remaining; —, no utilization. [b]GNB apparently excreted small quantities of these compounds.

cretory product utilization and that utilization of amino acids was greater than that of organic acids. Another finding of interest was that the combined activities of the four bacteria served to essentially eliminate the products excreted during algal growth. Other experiments demonstrated that algal excretory products are metabolized by bacteria as rapidly as they are liberated (Vela and Guerra, 1966). Depending on the experimental conditions, algae excrete up to 50 per cent of the organic material produced during photosynthesis (Fogg and Watt, 1965) and as a consequence support a luxuriant bacterial population. In streams receiving only inorganic pollution, dense algal growths could support sufficient bacteria that oxygen depletion would occur without additional organic pollution.

The results reported are incomplete and certainly do not solve the complex problems involved in the biology of water pollution. It is clear, however, that experimental analysis in the laboratory can lead to a better understanding of the relationships and mechanisms operating in natural systems. Laboratory data undoubtedly cannot be applied quantitatively to streams and lakes. However, the principles operating should be applicable in some form. Factors in natural systems that serve to modify the established relationships should also be subject to experimental analysis.

The effects of pollution on our large, complex water systems must be studied, but for experimental analysis and establishment of principles, the least complicated should be the systems of choice. Although such bodies of water as our Great Lakes, large rivers, and Galveston Bay need and require ecological study, definition of variables would be a formidable task. To meet our long-range goals of understanding and controlling aquatic ecologies, more definable systems must be used as experimental models.

If possible, the experimental system should be representative of the major water resources of the geographical region, which in this area is where fresh and salt water intermingle. According to Stanley A. Cain, " . . . estuarine systems . . . are among our most important, least understood, and most misused ecological complexes. They are important because they are so often extremely productive biologically; because they provide conditions necessary for breeding grounds, nursery areas, and feeding and resting places, for myriad forms of life; and because they are interesting, attractive and rewarding places for people to fish, hunt, boat, and enjoy living things."

The Rice University contribution to Environmental Science and Engineering and pollution control should be and is in the areas of teaching and research. The present program and future contributions to the betterment of the regional environment would be significantly enhanced by development of the Rice University Clear Lake facility into a center for education and research in estuarine ecology.

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