Introduction to Environmental Science and Technology

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Preface

It would be difficult to overemphasize the importance of population, pollution, and resource depletion as primary factors which limit the range of probable alternative futures still available to mankind. As we enter the last quarter of the twentieth century, it is becoming increasingly necessary for policy makers to become aware of these environmental constraints and to include them in their decision-making processes.

The first environment books were largely nontechnical in nature and served the purpose of increasing the public's awareness of our worsening situation. However, it is becoming apparent that to convert that awareness into action requires a more quantitative understanding of our environmental problems, and to meet that need universities across the country are introducing environment courses of one sort or another, frequently in their engineering or physics departments.

It has been my experience in teaching such courses at both the University of Santa Clara and Stanford University, that one of the most challenging aspects of the problem is to find a way to present technical material to an audience composed of students from every department of the university. I have found that the best approach is to rely heavily on graphs, tables, and illustrations, and to use equations only infrequently. That has been the approach taken in this book.

The book is divided into four parts. In the first, an introduction to some basic but important principles of ecology is presented, followed by an analysis of population growth and a discussion of some of the problems encountered in trying to provide an adequate food supply for our growing population.

In the second part, water pollution is discussed, with an emphasis on how man's activities can overload the natural ability of a body of water to purify itself. The importance of proper water and sewage treatment to public health is described along with the principles of operation of modern treatment plants.

In Part III, the problems associated with air pollution are presented with an emphasis on the five principal types of emissions. A chapter on air pollution meteorology is included in which the processes which cause the formation of inversion layers are described along with the possible effects of air pollution on climate. The technology of air pollution control, with an emphasis on the automobile, is included.

Part IV discusses energy and raw materials, the essential ingredients of our technological world. While the population and pollution aspects of our environmental problems have been generally accepted, it is only just now that the importance of resource depletion is being acknowledged. The problem is treated as a combination of growing demand, dwindling reserves, and increasing environmental disruption associated with the acquisition and use of these resources. Considerable attention is given to the new and future sources of electric energy: nuclear fission, fast-breeder reactors, and geothermal, solar, and fusion power.

The material has been written so as to be understood by anyone having a fairly simple science background which, ideally, would include a little chemistry, biology, physics, and mathematics (calculus is not necessary), although none of these is essential. At the end of each chapter, questions have been included; some of these are qualitative, but the majority are reasonably straightforward numerical calculations.

There have been a number of people whose assistance in the preparation of this material I gratefully acknowledge. Most especially, I would like to thank John Randolph of Stanford University for his many helpful criticisms and suggestions, as well as Professors Alfred W. Hoadley of the Georgia Institute of Technology, Alonzo W. Lawrence of Cornell, and Dragoslav M. Misic of California Polytechnic State University, San Luis Obispo. I also take pleasure in acknowledging Professor Shu Park Chan of Santa Clara for arranging the financial support for this project through a grant from the Sloan Foundation.

Santa Clara, California *Gilbert M. Masters*

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Part I

Ecology and Population

Chapter 1

Some Principles of Ecology

Relative to the history of all forms of life on earth, man is a recent phenomenon. Perhaps 2 billion years ago, algae were already releasing oxygen into the atmosphere through photosynthesis, thus helping to create the conditions that were necessary for the higher forms of life which followed. Man appeared much later, somewhere around 2 million years ago, but his numbers and his effect on the biosphere remained relatively small until the invention of agriculture some 8000 years ago. We can use that date as the beginning of man's manipulation of nature, the unwanted side effects of which, are the subject of most of this book.

Before proceeding to the study of man's impact on the earth's environmental systems, we need to consider how those systems normally function; that is, we need to study *ecology*. The word *ecology* was coined about 100 years ago from the Greek *oikos*, which means "house," and has come to mean the study of "the totality or pattern of relations between organisms and their environment" (Webster's Unabridged Dictionary).

1.1 *Ecosystems*

There are several important terms which need to be defined before proceeding. A group of individuals of one kind of organism is called a *population* and all of the populations living in a given area form a *community*. The community and the nonliving environment with which it interacts is an *ecosystem*. And if we consider all of the earth's living organisms interacting with the physical environment as a whole, then we are talking about the *ecosphere* or *biosphere*.

Ponds, streams, meadows, and forests are typical ecosystems that are frequently studied, but for now, let us examine the major components that exist in any ecosystem and see how they operate together.

The initial source of all of the energy used by an ecosystem is the sun. Green plants capture solar energy during photosynthesis and store it in chemical form for subsequent use by the plant itself or by any other organism that consumes the plants. The plants are called *producers* or *autotrophs* (self-feeding) while organisms that feed on the plants or on each other are called *consumers* or *heterotrophs* (other-feeding). The consumers can be further subdivided as shown in Figure 1.1. This linear description of feeding relations is called a *food chain* and each level is called a *trophic* level. We will see later that at each trophic level so much energy is converted to heat and lost that food chains seldom have more than four or five levels. A simple four-level food chain might be

plant → insect → frog → man

In addition to the producers and consumers, the biotic (or living) portion of an ecosystem must have *decomposers*. The decomposers, which are mainly bacteria and fungi, derive their energy from the waste products and dead organisms in the ecosystem, and in doing so perform the invaluable service of converting complex organic molecules into simple inorganic forms for reuse by the producers.

Figure 1.2 shows the movement of energy and nutrients (nitrogen, phosphorus, sulfur, etc.) through an ecosystem. There are two fundamental points which should be emphasized here. The first is that nutrients move through the ecosystem in a cyclic fashion. As they do so, they are not degraded in any way and hence can be recycled over and over again. Later in this chapter we will trace the movement of several of the most important nutrients through the biosphere in what are called *biogeochemical cycles*. The second point is that energy flow through the ecosystem is *not* cyclic and is in effect a one-way process. Energy is employed by organisms to fuel their movements and growth and is subsequently lost as heat. Thus energy must be supplied continuously by the sun to keep

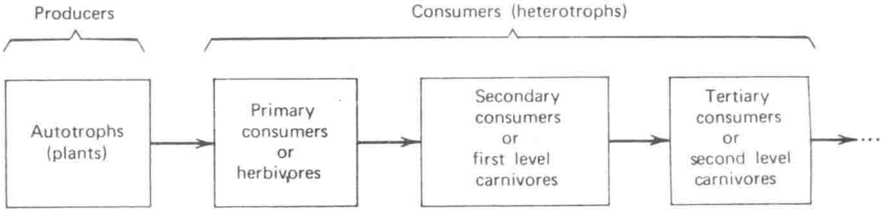

FIGURE 1.1 Various designations for each of the trophic levels in a food chain.

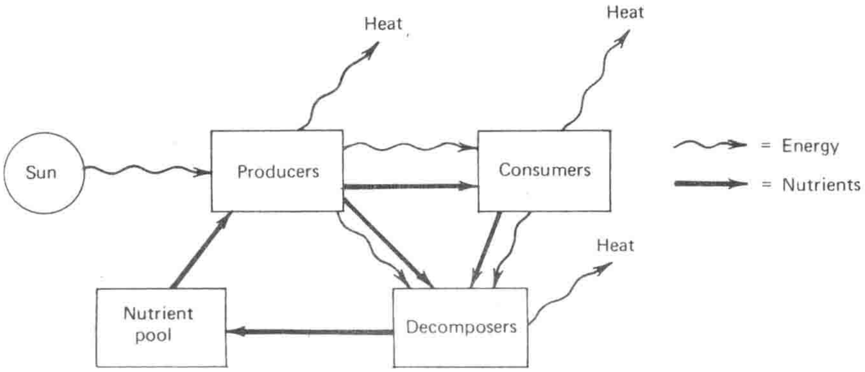

FIGURE 1.2 Nutrients move cyclically through the ecosystem but energy must constantly be renewed by the sun.

the system operating. Both of these important concepts will be discussed in detail in succeeding pages.

Figure 1.3 illustrates some of the many ways in which man's activities can upset the balanced operation of an ecosystem. Air pollution not only damages plants but also reduces the amount of sunlight reaching them. On the other hand, combustion of fossil fuels increases the carbon dioxide in the atmosphere which increases photosynthesis. Pesticides and preda-

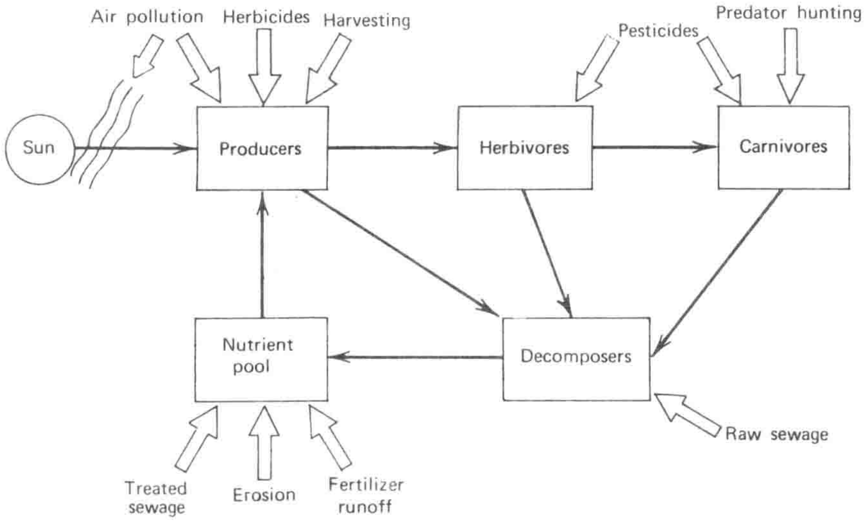

FIGURE 1.3 Some of the ways man's activities can upset ecosystem balance.

tor-eradication programs alter the balances among the consumers. The dumping of raw sewage into aquatic ecosystems increases the activities of decomposers and can overload the ecosystem. Treating the sewage in conventional sewage plants and releasing the effluent into aquatic ecosystems increases the nutrient pool which can lead to excessive growth by the producers.

These are some of the problems which will be addressed in subsequent chapters.

1.2 Food Webs and Population Stability

It is convenient to talk of food chains but clearly in nature, things are not so simple. Each link in a food chain interconnects with many other food chains and the complex set of feeding relations that results is called a *food web*, a relatively simple example of which is shown in Figure 1.4.

It is conventional wisdom in ecology to suggest that the stability of a food web is related to its complexity. Complex food webs tend to be stable, that is, the number of individuals in each population tends to remain nearly constant. Conversely, minor perturbations in a very simple food web can cause such major fluctuations in population sizes that species may even be driven to extinction.

Consider, for example, the simple two-species food chain:

$$\begin{array}{ccc} \text{prey} & & \text{predator} \\ A & \rightarrow & B \end{array}$$

If the population of A should start to decrease, we would expect the shortage of prey to cause B's population to also drop. As B's population decreases, the lack of predation would cause A's population to suddenly increase. Since its food supply would now be more abundant, the population of B would also increase, perhaps to the point where the increased predation would cause A's population to once again begin to decrease.

It is easy to see then, that for such a simple food web, oscillations are very likely to result. Figure 1.5 shows such oscillations in the populations of the lynx and its principal prey, the snowshoe hare, in Canada. Although apparently more than just predation is involved here, the populations of the hare and the lynx do closely follow each other, with periodic crashes occurring every 9 or 10 years.

Consider how even a slightly more complex food web can help to compensate for a change in one of the populations. For example, if the