Inquiry into Environmental Pollution

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A Note to Teachers

This book is intended to be useful in stimulating and supporting student activities related to the study of environmental pollution. The activities may vary widely, from laboratory work to field studies, from library research to class debates and discussion. The book is not, in itself, intended to be a major source of information; the supply of factual material on ecology and pollution is already immense and there seems to be little point in adding to it. Thus, our goal is to provide a *teaching* book, one that asks productive questions and suggests helpful exercises. Naturally, you will want to supplement it with samples from the rich supply of pamphlets, booklets, periodicals, and films related to the subject.

It is a common adage amongst teachers that there is no one single "best way" to teach something. Teachers tend to find styles and methods that work well for them. *Inquiry into Environmental Pollution* was meant to allow the individual teacher to use his own preferred styles. Many sections of the text will be suited to advance reading assignments followed by class discussion and seat-work. This can be done in as directive a style as is desired. Or it can be done in the inquiry mode if the class and teacher are moving in that direction. The text does not particularly demand one style or the other, although the author does confess to a personal bias in this respect.

There is strong emphasis placed throughout the book upon the gathering and analysis of evidence. There are many experiments suggested, and the bulk of them are simple. It seems best suited to the temper of our time not to give the experiments as specific recipes and not to "give the show away" by telling what the official observations are. So many teachers today are planning the laboratory exercises with their students in thorough pre-lab discussions that it appears most helpful to only outline the laboratory activity here and to leave the specifics to the teacher to suit the particular situation in which he finds himself. In the same way, the laboratory activities are usually followed by questions, and each investigation is intended to speak for itself. Here again the teacher's personal guidance of the post-lab discussion, with appropriate scientific rigour applied to controls, assumptions, and interpretations, cannot be replaced by material in a textbook.

It is probably self-evident that it will be a barren course in environmental pollution that does not range beyond the boundaries of the classroom. There is a continual thrust in the text to urge students to look at their own and neighbouring communities. Field trips and industrial visits for whole classes or small groups will greatly enhance the use of the text. It may be productive to have an outside person spend some time with your classes. Again, you will find that the content and approach of this book is highly compatible with the use of community resource personnel. Finally, there is provision in Chapter Five for the involvement of teachers of subjects other than science. I have tried to make this involvement seem easy and natural without pushing it so hard as to appear artificial.

The text takes the view that it is more desirable to open doors than to close them. Thus there are frequent suggestions that students should speculate, or add to a list, or find other alternatives than those mentioned, or even to seek flaws in the text itself. Many of the questions asked do not have simple, direct, cut-and-dried answers that everyone will accept. But then, neither have our pollution problems. It seems appropriate to the subject to provide more questions than answers and to insist that sound reasoning, based on evidence, be the criterion for good answers.

Reference has been made to the feature of not demanding any one particular teaching style. An implication of this feature is the variability in the sequence and emphasis of topics. Many teachers prefer to use the sequence given, omitting occasional sections if time presses. But it is quite possible to use other sequences, and I have tried to make it easy for the teacher who so wishes, to move about through the text. In order to help present an overview of the text and to see some of the possible sequences, an outline follows, together with a flow chart of some possible paths.

Outline of the contents

Chapter One describes the mechanisms of an ecosystem and plunges directly into some pollution implications. Three ecosystems are described and optional laboratory work is suggested. The concepts of abiotic environment, producer, consumer, decomposer, matter cycles, and energy flow are introduced. This chapter will probably be the commonest place to start.

Chapter Two deals with water in the ecosystem. It is difficult to know how much of the chemistry of water is mandatory as background for the ecological explorations to follow. Certainly a course in environmental pollution is an excellent vehicle for some chemistry, and it seemed reasonable to assume that some teachers would have classes ready and able to pursue some chemical details. It also seemed probable that in other cases, the chemical details might be found peripheral to the main subject, and too time-consuming. This problem seemed especially acute in laboratory work requiring much technique. The matter was resolved by writing a reasonably general treatment of water as a solvent both of acids-bases and of gases. There is a strong laboratory emphasis and a continual theme of reference to pollution problems. Much of the laboratory work is useful for the experiments in Chapter Three.

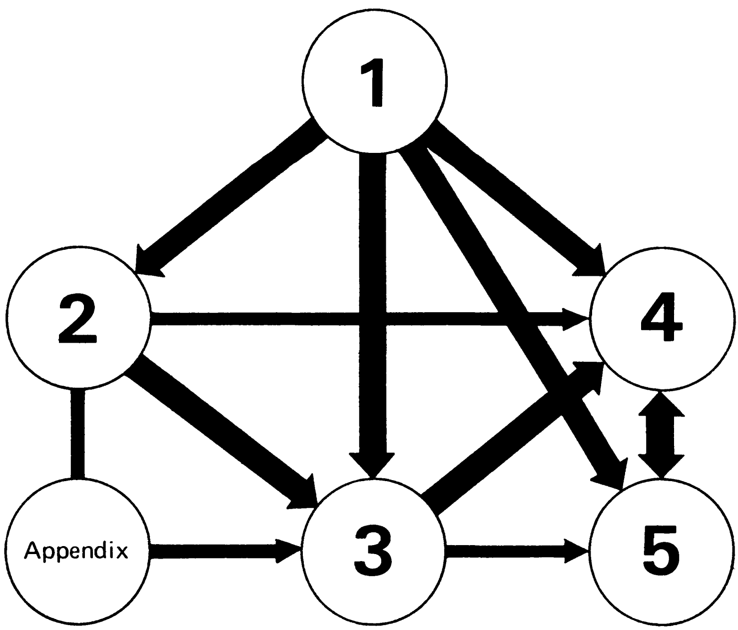
The more detailed, technical laboratory work for Chapter Two is placed in the Appendix. Thus, those who have the time and inclination can pursue that line, but it is *not* essential for the understanding of the rest of the text.

Chapter Three deepens the conceptual development of ecosystem relations by examining only producers and decomposers. There is laboratory work on photosynthetic production and on respiration, emphasizing the gas relations. Decomposers are sampled in the environment and their gas relations are explored.

Some factors affecting the growth of both are tested in the laboratory. If the lab work is to be done, appropriate parts of Chapter Two should be taken first.

Chapter Four completes and complements the previous chapter by describing the consumer as a modifier of the ecosystem. That does not mean that the chapter could not be taken on its own, out of order, if desired. Fish, beavers, and men are the examples studied. The emphasis is placed on men as consumers, and on the possibilities both for destruction and for improvement of the environment.

Chapter Five deals entirely with the human pollution situation, trying to use and apply general ecological concepts, but venturing also into social and political realms. Each level of society is examined through a series of case studies, which teachers



Flow chart. Some possible sequences for studying the chapters in *Inquiry into Environmental Pollution.* Other sequences are possible, especially if chapter sections are rearranged and taken in new combinations. (Many sections are written in a way that will permit rearrangement, if desired.)

may treat as lightly or as deeply as seems best. Successful learning with any case study in this chapter is not dependent on the completion of any other one.

Acknowledgements

No matter how short a book is, it always seems to take more time than is available. The preparation of this one was greatly assisted by members of my family, especially Lyn Horwood. Very helpful detailed criticism was received from teachers in the field, from education students at Queen's University, and particularly from Dr. J. E. Guthrie of Whiteshell Nuclear Research Establishment, Manitoba. I am greatly indebted to them all.

R.H.H.

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CHAPTER ONE

The System of an Ecosystem

1.1 Setting the Scene

Every human being occupies some part of a complicated organization. A group of students, brought together in a particular place, make up a school. The students, in turn, are grouped into a variety of classes assigned to particular teachers, and the teachers themselves are responsible to a small number of local administrators. It is interesting to extend this idea to include the entire school system of which you are a part.

In a similar way you could think of the organization *within* one individual person. This will lead you to picture smaller and smaller (or lower and lower) levels of organization. For example, each of us is a group of connected systems (digestive, nervous, etc.). The systems are built from organs made of tissues, which are, in turn, made of cells, and so on down to the fundamental particles of matter. And as you move down to successively lower levels, when do you leave the region of biology and enter the realms of chemistry and physics? Is there a level of organization beyond which you cannot go?

The point of these ideas and questions about levels of organization is to set the scene for the topics you are about to study. It will be very helpful if you can understand, in a general way, the level of organization at which you will be working. And it

<u>Cells</u> form <u>tissues</u> form <u>organs</u> form <u>systems</u> form <u>individuals</u> form <u>populations</u> form <u>communities</u> form <u>ecosystems</u> form <u>biomes</u> form <u>biosphere</u>.

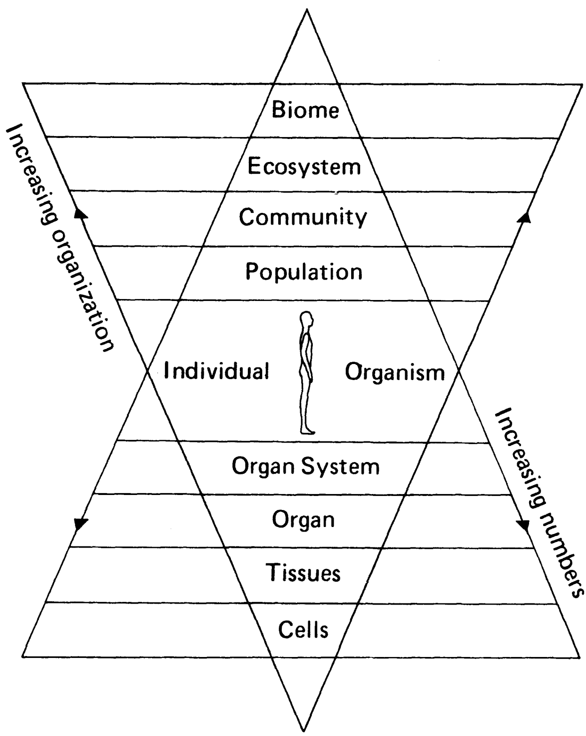


Figure 1:1 Diagram of the organizational structure of the world of living things. Complexity increases from bottom to top; the number of units increases from top to bottom.

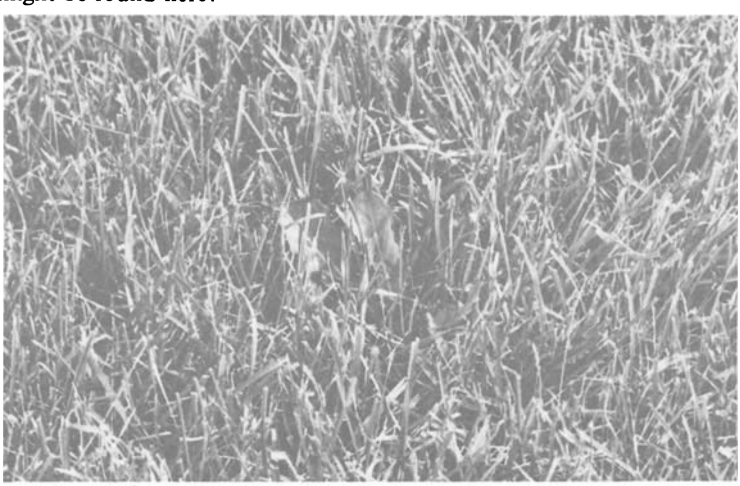
will help you to do that if you can thoroughly grasp the idea that living things can be organized into a series of groupings in a graded order. Figure 1:1 illustrates the organizational scheme that will be considered.

You will recognize the series of systematic groupings of cells into tissues, of tissues into organs, and so on up the scale to individual *organisms*. In a like way, groups of similar organisms make up a *population*, and groups of different populations form a *community*.

For example, a lawn might be thought to be a population of grass plants. On closer examination of the lawn, you might find dandelions, plantain, and earthworms, to mention but a few other (and different) kinds of living individuals. Thus a lawn can be regarded as a community of several different populations. You will find it helpful and interesting to see how well this biological use of the word "community" fits in with our ordinary everyday use of the same word as applied to a town, village, or suburb.

Let us examine the lawn community more carefully. If we choose to include the soil, the air, and the other physical parts of the surroundings, then we will have moved to the next level of organization — the *ecosystem*. Finally, all of the ecosystems

The lawn community. What living things other than grass plants might be found here?



make up the entire realm of living things, technically known as the *biosphere*.

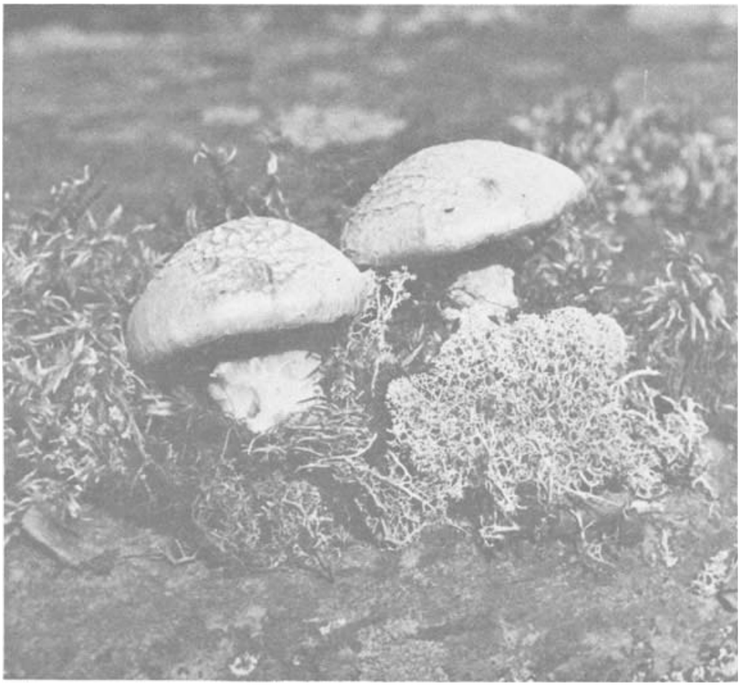
Pollution and its effects upon the environment are the theme of this work, and since these relate most clearly to the ecosystem level of organization, we shall look directly at the structure of ecosystems.

1.2 The Ecosystem

Each living thing, in the simplest view of it, needs a place to live and something to eat. Those two basic needs are filled by a complex interaction between the non-living *physical* components of the world, and its living *biological* inhabitants. The physical aspects, such as temperature, light, precipitation, wind, and soil, are called *abiotic*, a term which, logically enough, means non-living. The *biotic* components are those comprising the set of all living things in the system.

Consider a particular mushroom. In what kind of place does it live? Some key abiotic factors include soil type and acidity, the amount of humus, soil drainage, and the climate. There are many others. See if you can list some of them. Some of the biotic factors influencing this particular mushroom include the plant cover, competing mushrooms, and an adequate supply of "food".

Now think about the mushroom itself. On what does it feed? The thread-like cells that form the bulk of the fungus body twine and branch through the soil. There they produce digestive fluids called *enzymes* which break down complex organic molecules in the soil into simpler forms. The simpler molecules are absorbed by the mushroom cells and incorporated into the living mass of the mushroom. All of this would be quite straightforward providing you continued to regard the mushroom in isolation. But if, mentally, you were to back away from the mushroom, so to speak, you would have to cope with at least two problems. First, where do the molecules of organic matter in the soil come from in the first place? And, second, since mushrooms don't last forever, what finally becomes of them? Answering questions like these leads us to consider that system



Forest mushrooms. How much of the mushroom plant is visible here? To which ecosystem component do mushrooms belong?

of interactions which biologists call an ecosystem.

To illustrate the point, think about this experience with a particular mushroom. The mushroom was a *Boletus*-type, which was found about eight feet above the ground, wedged between the trunk and a branch of a tree, not far from the banks of the Whiteshell River in Manitoba. Subsequent investigation showed that squirrels store mushrooms in places such as this and eat them either fresh or dried. Thus, for that particular mushroom, one can say that its destiny was to be eaten by a squirrel.

In a similar way, some careful digging and further investigation suggested that the mushroom derived its food from decaying leaves and animal manure in and on the soil. Thus, for this mushroom, it can be said that the organic matter upon which it fed came from plants such as the aspens and the birches, which were common in the area, and the wastes excreted by animals such as porcupines, deer, mice, and even squirrels.

Now you can see that it is impossible to think about the life of one single creature without also thinking about a whole series of other biotic and abiotic factors. The mushroom has a complex set of relationships with the trees, with the animals, and with the abiotic environment. That set of relationships forms an ecosystem, and the kinds of relationships involved are illustrated in Figure 1:2. To which components of the ecosystem do mushrooms, aspens, and squirrels belong?

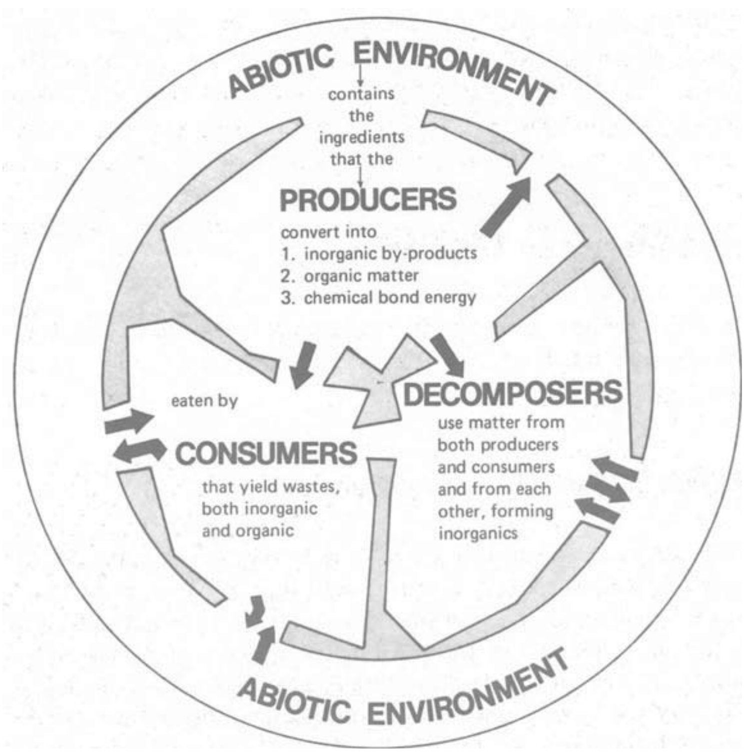


Figure 1:2 Schematic sketch showing the relationships between the various components of an ecosystem.

If the interconnections found among various living things and the physical surroundings are fairly represented by Figure 1:2, then it should be possible to use one's knowledge of particular plants and animals to check the figure, or to use the figure to predict observable relations between plants and animals. The accuracy of the figure can be tested by taking, as a start, organisms such as grass in a prairie, sunfish in a slough, or chipmunks in a park, and seeing how they fit into the ecosystem scheme outlined in the diagram. The relationships can be tested experimentally by establishing a variety of aquaria or terraria.

By now it should be clear that no organism lives in isolation. Rather, each individual depends on its physical environment, and other organisms, for the necessities of life. In turn, each organism contributes something to other organisms and to the abiotic world. It is the role of each living thing to consume and, ultimately, to be consumed.

1:3 Living Is Polluting

In this section, three specific ecosystems are examined very briefly with much left for each of you to do on your own, or with the class.

CASE 1: The Wine Ecosystem

The grapes are crushed, forming a rich, red, sweet juice. A culture of active yeast cells is stirred into that complex mixture of sugars, acids, tannins, and pigments that form the juice. Within a few days, the life of the yeast becomes evident to the winemaker, first by the froth of bubbles appearing on the surface and then by the rich, yeasty odour that hangs above the vat. As fermentation goes on, the thickly scummed surface of the young wine heaves and bubbles. The temperature rises. After ten days or so the activity slowly subsides and the winemaker transfers the new wine to other containers. Some months later he obtains a sparkling, ruby-clear fluid resting on the layer of dead yeast cells that formed it.

It is impressive to see those yeast cells, once so vigorous, finally so inert. The yeast cells were very much alive, absorbing sugar from the solution and changing it chemically into carbon dioxide and alcohol. For most of their lives, the yeast cells are unaffected by that chemical change. The most important thing they gain is the energy made available inside each yeast cell as the sugar is used up. This energy enables the yeast cells to use other grape substances for growth. And, like most living things, yeast cells produce new yeast cells, each of which repeats the activities of the parent.

You may see that there are several possible explanations for the yeast cell population eventually dying out, rather than continuing to ferment the wine forever. One possibility is that the cells become too crowded to be able to live properly. A second could be that the cells may have used all of the sugar in the juice. A third, that the products of the yeast's own life processes (carbon dioxide and alcohol) may have built up to poisonous concentrations.

Each of these three possibilities can be tested experimentally. When densely populated yeast cultures are compared with sparsely populated ones, approximately equal rates of cell division in each culture indicate that crowding is not an important factor. However, the simple addition of more sugar to the finished wine results in renewed fermentation, suggesting that the earlier inactivity of the yeast cells was due to a lack of its basic energy food.

But even this is not an entirely satisfactory answer because, once again, the fermentation eventually stops, and adding more sugar will not stimulate further fermentation. Other equally simple experiments have been done that suggest there is a distinct upper limit of alcohol concentration in their surrounding environment that prevents yeast cells from functioning properly. This ought not to surprise us, for too much alcohol is as toxic for yeasts as it is for man. The significant point is that the yeast acts as the agent of its own destruction. Production of the alcohol of fermentation is one of the final products of the living process of yeast cells. Yeast pollutes its environment as it flourishes and finally pays the price.

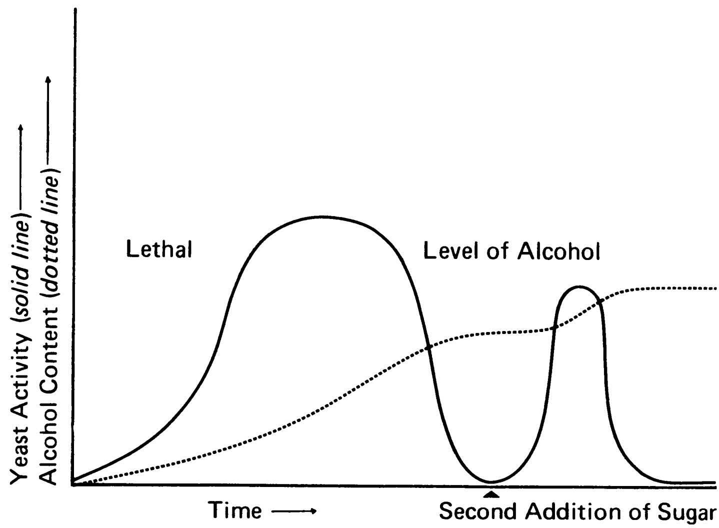


Figure 1:3 Graph showing the yeast activity and alcohol production with time. In this case the original fermentation stops, but is renewed after the second addition of sugar. The additional alcohol produced raises the level to a point that the yeast cannot tolerate. The yeast activity stops a second time regardless of whether there is still sugar present or not. If other substances in the wine system are present in short supply, or in overabundance, the graph might look quite different.

Questions

1. "One man's meat is another man's poison."
   The wine ecosystem is not perfectly stable, or "dead", even after the yeast has become inactive. Investigate the organisms that live in wine. What does the information gathered about these other organisms tell us about environmental pollution?

2. Consider newly fermenting grape juice as an ecosystem. What components of the wine correspond to abiotic factors, producers, consumers, decomposers?

3. One could argue that the wine ecosystem is "unbalanced", i.e., not able to maintain itself. Invent a balanced ecosystem, starting with freshly pressed grape juice and yeast but adding whatever other ecosystem components you like.

CASE 2: The Bushlot Ecosystem

The wine ecosystem is a highly specialized and restricted case involving one organism, or at the most two. The ecosystem that exists in a bushlot is much more complicated, there being so many different kinds of organisms involved, and it will be difficult to avoid "missing the woods for the trees". All the same, it is possible for us to take a kind of simple overview of the bushlot ecosystem and identify the sources of natural pollution there.

An early April walk through a deciduous bushlot can be a very pleasant thing. The trees are bare; there is no undergrowth; the walker can move relatively easily and has a clear view of the sky. To the casual viewer, all appears dormant or dead, but to the more observant there are signs of resumed activity in the swelling of tree buds and the occasional patch of greening moss. The observer interested in pollution might be impressed by the thick layer of debris or litter on the ground. At home, that collection of leaves, twigs, nuts, and branches is usually raked carefully together and burned. In the bushlot, on the other hand, it stays in place, building up a layer of material that gradually breaks down and decomposes. One could argue that the litter is a form of pollution that changes the quality of the environment. Would you agree that the bushlot ecosystem would be rather different if the litter were systematically collected and burned, year after year?

The trees, as dominant members of the bushlot ecosystem, could also be accused of a form of pollution acting upon the abiotic component. On an early April walk through a bushlot one can "see the sky". Sunlight penetrates to the bushlot floor with little interruption. The situation is very different some two months later when the canopy of the trees is in full leaf. A creature living on the forest floor might well cry out "Shade pollution!" in somewhat the same way that people who live near airports cry "Noise pollution!"

Questions

1. Classify eight or ten prominent members of the bushlot ecosystem as abiotic, producer, consumer, or decomposer.
2. (a) What events would terminate the existence of a bushlot ecosystem? (Four or five different ones would be sufficient.)
   (b) Describe the eventual fate of a bushlot if none of the events in (a) took place.
3. The theme of the bushlot description is the basic notion that all living things pollute their environment in some way. This is a debatable idea. Prepare one set of arguments to support the idea and a second set to show that the idea is wrong.
4. It is suggested that systematic, regular removal of litter would, in the course of time, significantly change the bushlot ecosystem. Speculate upon the kinds of changes that might occur. Give reasons for your speculations.

CASE 3: The Aquarium Ecosystem

Keeping an aquarium is a very common hobby. It is so common that most department stores routinely stock aquarium supplies and often have a knowledgeable and experienced sales person to assist the customers. The aquarium provides a convenient and compact ecosystem for your consideration and, perhaps, for experimentation.

Anyone attempting to set up an aquarium pays a good deal of attention at first to the abiotic components. The gravel is washed free of dust and debris. It may even be sterilized to avoid the introduction of undesirable organisms. The water is carefully collected, aged, and adjusted with regard to salinity, acidity, hardness, and other qualities. Provision may be made for the maintenance of the water temperature at levels above, or possibly below, normal room temperatures. Some sort of mechanism for filtering and aerating the water is usually provided.

The new aquarium is normally stocked with plants for a week or so before the fish are added. In this way the plants become established, and the water temperature and aeration machinery can be tested. Finally, fish are introduced and the aquarium is complete. It is the smoothly operating aquarium that may be of special interest to students of environmental quality. What makes the aquarium system operate "smoothly"? The visitor sees an apparently stable but dynamic system. The aquarium owner, however, knows that some attention must be paid to it regularly, or the ecosystem will break down. Perhaps it is possible to imagine setting up an aquarium so large that it would look after itself reasonably well, or take so long to run down that the person starting it wouldn't see its collapse within his lifetime.

Questions

These questions will be best answered through reference to personal experience with aquaria or through discussion with persons who have set them up.

1. Identify the major components of an aquarium ecosystem according to the classifications: abiotic, producer, consumer, and decomposer.

2. The "aged" water that aquarists prize not only is old but also has had fish and plants living in it.
   (a) How does "aged" water differ from fresh tap water?
   (b) Which type of water, "aged" or fresh tap water, would you consider to be polluted and why?

3. "It is difficult to overfeed the fish but it is easy to overfeed the aquarium." What does this statement mean in relation to the aquarium ecosystem?

4. (a) What possible changes can you picture occuring in an aquarium ecosystem in response to an *increase* in each of the following components one at a time: oxygen, salts, phosphate, light energy, mosquito larvae (or other aquatic larvae), carbon dioxide?
   (b) If possible, check your prediction against actual cases.

5. Reconsider Question 4. How does the aquarium ecosystem

respond to *decreases* in each of the components mentioned? (You might prefer to add to the list of components or to remove some.)

1.4 Going Around in Circles

As has been observed, one can argue that every living thing pollutes its environment. The life processes inevitably lead to changes in the quality of the surroundings. Wine yeasts replace the sugar content of grape juice with alcohol and carbon dioxide. Trees cast shade upon the forest floor and produce a litter of dead leaves and branches. Fish eat tiny animals (*zooplankton*) or microscopic plants (*phytoplankton*) and excrete wastes. Living is polluting.

Within the boundaries of our usual understanding of the term "pollution", however, natural events of this kind, if not considered "good" things, are at least not looked upon as "bad" things. As a result, the distinction between natural (i.e., good or acceptable) pollution and artificial (bad or unacceptable) pollution becomes a fairly basic problem. If changing the environment is an unavoidable result of being alive, then we humans must face the fact that some pollution is inevitable. Our attention can then shift from an attempt to prevent pollution altogether to the more realistic goal of determining what kinds and quantities of pollution we can continue to live with.

Several questions emerge. Why do we not normally consider a working wine vat, or a bushlot, or a balanced aquarium to be polluted? Why is pollution peculiarly a problem of the 1970s rather than of all time? Is it possible that the recognition of a polluted environment is more a matter of taste than of fact?

One of the major factors that makes natural environmental pollution acceptable is the *circular* nature of the process. A second factor is the dynamic kind of balance that exists in most ecosystems between the principal components. You can see that a kind of reverse process is set in motion when one creature's waste products become another organism's food. The pollutant does not long remain unaltered in the environment. You can also see that simple survival in the natural world ensures that the one creature's waste products will be used up by other organisms just about as fast as they are produced. And if they are eaten more slowly, the accumulating waste products soon become food for more and different organisms. Look again at Figure 1:2 and trace the many channels by which potentially

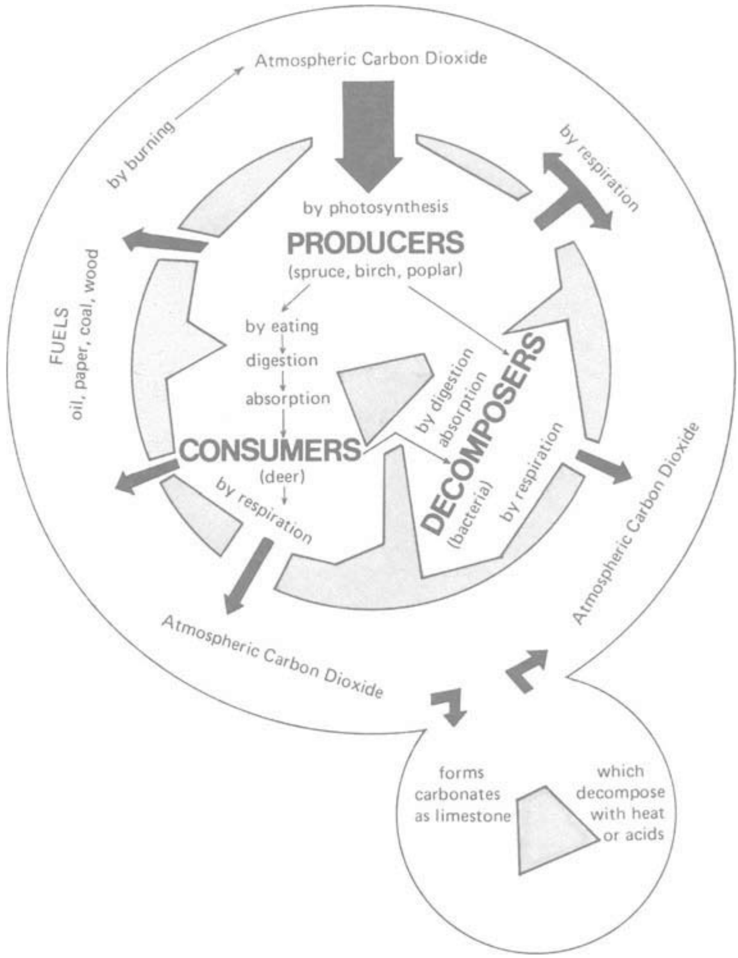


Figure 1:4 The carbon cycle. Note the difference in the number of routes generating atmospheric carbon dioxide compared with the number of routes consuming atmospheric carbon dioxide.

polluting substances are moved from one part of the ecosystem to another.

One of the points being made here is that matter, or chemicals if you prefer, *cycles* through the ecosystem. Almost every student learns at an early stage the details of the water cycle. There is a good probability, too, that you already know at least the outline of the carbon and nitrogen cycles. If you don't recall them very well, the carbon cycle is illustrated in Figure 1:4, and the nitrogen cycle is shown in Figure 1:5.

In any event, most matter is highly mobile within the ecosystem: moving, according to biological processes like absorption, gas exchange, and excretion, from one living thing to

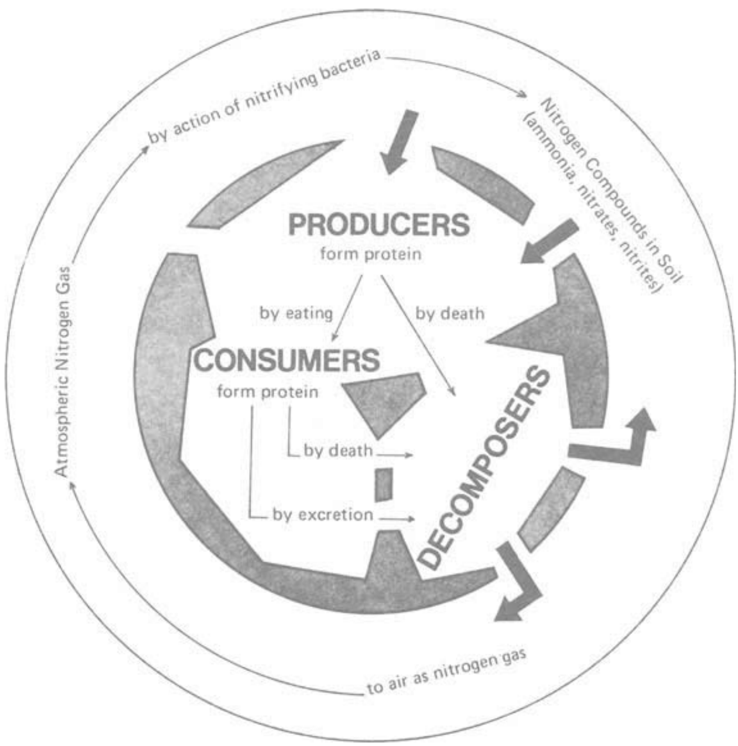


Figure 1:5 A simple version of the nitrogen cycle in the ecosystem. The nitrogen atoms are found in a variety of forms, as nitrogen gas or as relatively simple substances in the soil or as part of more complex molecules, such as proteins, within living organisms.

another, from the living to the non-living, and back again. As a challenge, you might care to work out a chart illustrating the cycling of some biologically important element such as sodium, calcium, or phosphorus. Or you might try chlorine, radioactive strontium, caesium or even potassium, starting with a potassium-rich substance such as fertilizer potash.

It is a fact of life that the relationships between the parts of an ecosystem ensure the re-use of nearly all, if not all, the chemicals involved. Natural pollution, which is the price of life, is reversed. Chemical substances do not accumulate to dangerous levels in nature.

All of this has a powerful bearing upon understanding the process of environmental pollution. And it is important for us, as humans, to have in mind both the idea that substances cycle continuously through effective ecosystems, and the idea that "balance" in an ecosystem implies equal rates of production and consumption of materials. The application of these ideas to the human situation is explored in Section 4.7.

1.5 How Fast Can the Cycles Turn?

The previous section emphasized the fact that matter is re-used in the ecosystem. The chemical substances that make up the biotic and abiotic world are changed as they are moved from one part of the ecosystem to the next. In studying pollution, it is important to ask ourselves what limits there are on the materials available for use. One can see that a producer is unable to use up more carbon dioxide than is available. If the carbon dioxide supply runs out, the producer stops its use of that substance, no matter how favourable other conditions may be. Of course, if the ecosystem could provide carbon dioxide faster, or in greater quantities, then the producer could increase its activity.

But how fast can the carbon cycle turn? If an imaginary producer needed to have ten times as much carbon dioxide as was normally available, the consumers and decomposers would need to work ten times as fast. Some single condition always limits the speed at which the matter cycles operate. There is a definite limit to the amount of raw materials available for use by each member of the ecosystem.

There are two points that need to be made. The first is that *man is a member of his ecosystem.* This fact is emphasized strongly in Chapters 4 and 5. The second point is that *man's use of substances is limited by the matter cycles in which he takes part.* There is a limit to the amount of raw materials that we can use. Someone has said that in Nature, there is no such thing as a free lunch.

You will find it helpful to work with these ideas by trying to diagram the oxygen cycle. As you do this, think about the ways in which people make large demands upon the world's stock of oxygen; not just for breathing, but for fires, engines, and the like. What possible conditions might limit our use of oxygen?

1.6 Running Down Forever

Matter goes around in circles through the ecosystem. Some of the air molecules exhaled by a football player in Regina may well be inhaled by a fan in Winnipeg on another day. The calcium of the soil becomes the calcium of milk. The water in one man's urine may appear, downstream, in someone else's coffee. It is possible to describe a "cycle" for every chemical in the ecosystem.

There is, however, one part of the ecosystem that does not cycle. It is energy. Energy enters the ecosystem primarily as light. The usable light energy is transformed into complex chemical bond energy by the primary producers and may be used later by the consumers, the decomposers, or even by the producers themselves. This use may result in the conversion of the chemical bond energy into other forms such as the energy of movement or electrical energy, or it may even be turned back into a form of light energy.

In any case, the conversion and use of chemical bond energy always results, eventually, in the formation of heat. Once energy becomes heat it is lost to the ecosystem. It cannot recycle because the producers have no way to convert heat energy. Some-

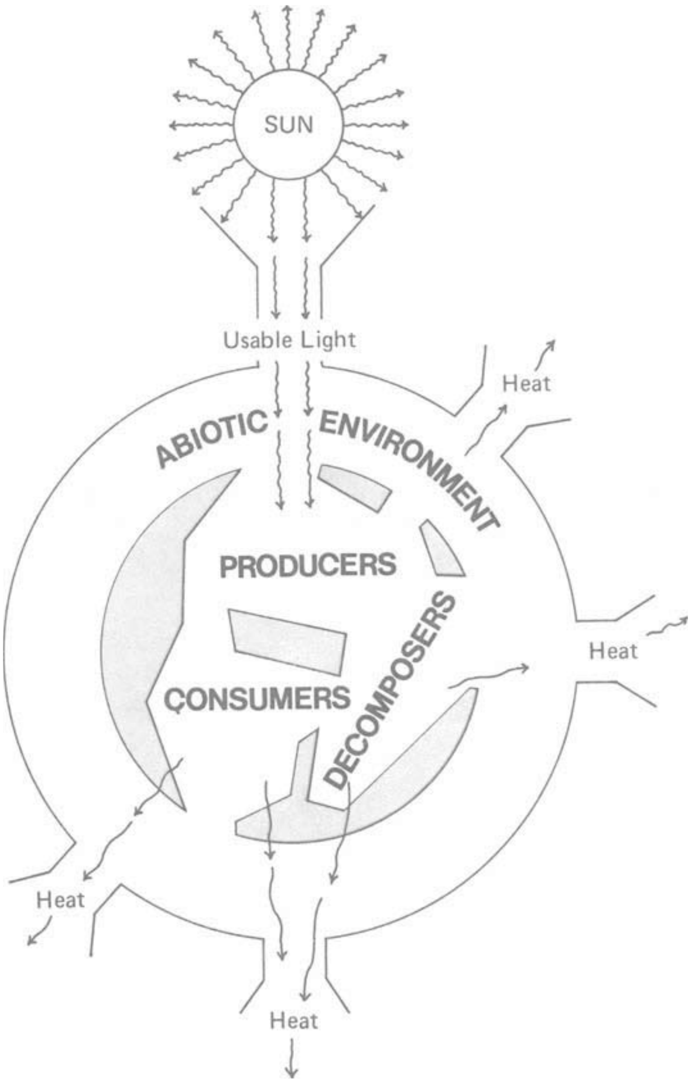


Figure 1:6 The ecosystem leaks energy.

one has said that heat is the lowest form of energy, and you can see that in this respect at least, that person is right.

Try to suggest at least four or five questions that arise from the previous statements. Two of them might be "Why doesn't an ecosystem get hotter and hotter?" and "If the ecosystem is always losing useful energy as useless heat, what keeps the chemical cycles and the ecosystem going?" These questions and others that you think of could serve as the basis for a class discussion. Figure 1:6 will help you to clarify your ideas about this aspect of the ecosystem.

Energy makes the ecosystem go in the same way that gasoline makes a motorcycle go, and one of the key points being made in this section is that *the energy that drives the ecosystem does not recycle*. Instead, a fresh supply of energy is always entering the ecosystem and there is a continuous draining of energy from it. Energy follows a one-way path through the ecosystem. This point is important because it touches close to the heart of many current pollution problems. Where do humans get the energy for their many activities? And what do they do with the heat that must invariably result? Chapter 4 deals more fully with these points.

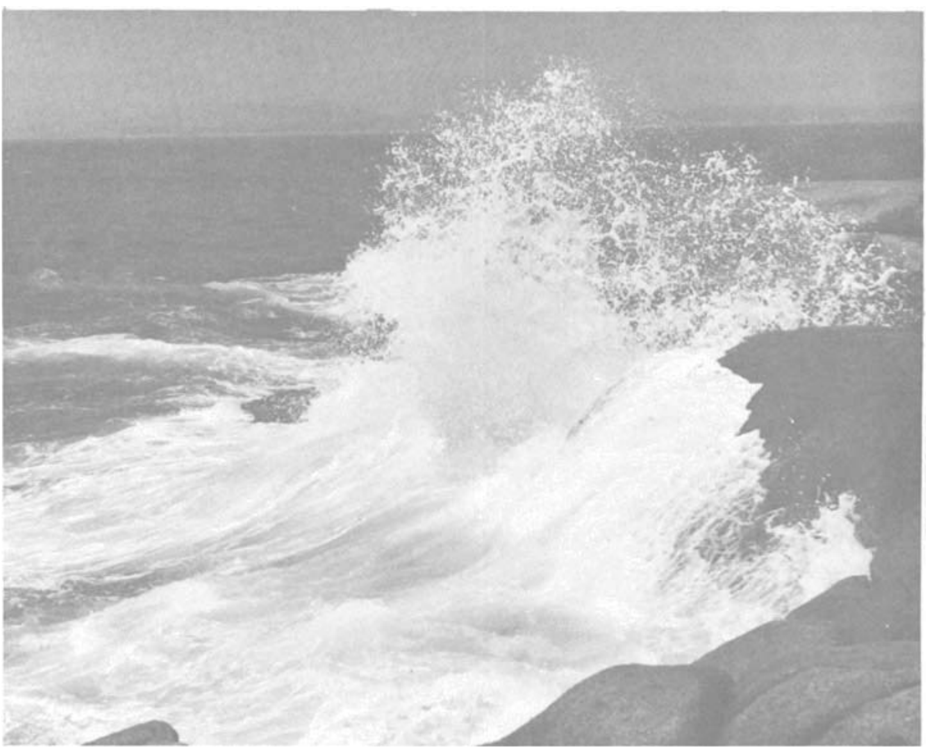
1.7 Where Next?

Your work in this chapter has involved thinking about the notion of an ecosystem. You have undoubtedly considered several examples of ecosystems and are familiar enough with the ways in which the parts of an ecosystem affect each other. You may have developed some definitions and drawn some diagrams, and have almost surely been confronted with some ideas that are difficult and puzzling, and that you have only half understood. Now you might say (if you haven't already said it) "So what?"

It is possible to provide an answer to that question that satisfies some people, but it is quite unlikely that it would truly satisfy everyone. Each person must content himself by pursuing the question in his own way, and there are several ways in which this book can be used for that purpose. For example, the class can continue directly on with Chapter 2, where the laboratory basis for the study of water pollution is begun. Or you might turn to Chapter 4, where specific ecosystems involving mankind as the polluter are described.

Questions

1. Look in some of the reference books listed on page 116 to find out what happened in Donora, Pennsylvania, in October of 1948 and discover how the ecosystem went wrong.
2. For the sake of argument, suppose that all the consumers in an ecosystem perished, and suppose, too, that no new ones could move in or evolve. What changes do you think would occur in the ecosystem?
3. Think about Question 2 again, but this time imagine that it was the decomposers that ceased to exist.
4. Consider what would become of the ecosystem if it lacked both consumers and decomposers.
5. Dr. A. E. R. Downe trapped mosquitoes in the Ottawa area during one year and tested the females to determine what kind of blood they had been eating. As expected, bird blood and mammal blood were both found, but amphibian blood was the commonest of all. This was taken to mean that most of the mosquitoes sampled took blood meals from frogs, toads, newts, and other such animals. Frogs, on the other hand, eat mosquitoes.
   (a) Diagram an ecosystem containing this kind of relationship between frogs and mosquitoes.
   (b) It is often possible to get a supply of mosquitoes, preferably as larvae and pupae, and frogs are also easy to obtain. Set up a terrarium ecosystem containing both a frog and mosquitoes.
   (c) What sort of proportion in numbers will be needed to have a "perfect balance" between frogs and mosquitoes?
   (d) Why is a "perfect balance" impossible to achieve?
6. The city of Timgad had an environmental problem. What can you learn about it?



CHAPTER TWO

Water in the Ecosystem

2.1 The Stuff of Tears

It is quite obvious, but still worth emphasizing here, that water is essential to life. Everyone is aware that the processes of life stop in the absence of water. Even those plants and animals that seem to have dispensed with the need for water by living on land or in the air have their lives regulated by the water supply. This, no doubt, is related to the fact that all known plants and animals maintain a very watery internal environment, even if they are quite dry outside.

Howland Owl, one of Walt Kelly's comic strip characters, expresses this idea very well. He says: "You don't realize how important water is — it's the home of fishes — the main ingrediments of rain — the basis of hot coffee — the stuff of tears."

2.2 Some Things Water Does

Try to think of some possible reasons for the importance of water in an ecosystem. Some may be able to think of only one or two; others may be able to come up with five or six. The important thing is to try to suggest as many possibilities as you can, on the basis of all the things that you know about water. Write your list on a piece of notepaper before reading on.

Once you have completed your own list, you should discuss it with your classmates and your teacher, and then compare it with the following list.

- easily forms a solid, a liquid, or a gas;
- holds a lot of heat without much change in temperature;
- the solid state (ice) begins forming at the *upper* surface of lakes and rivers;
- dissolves a lot of different substances;
- produces cooling when it evaporates;
- is not a good conductor of electricity.

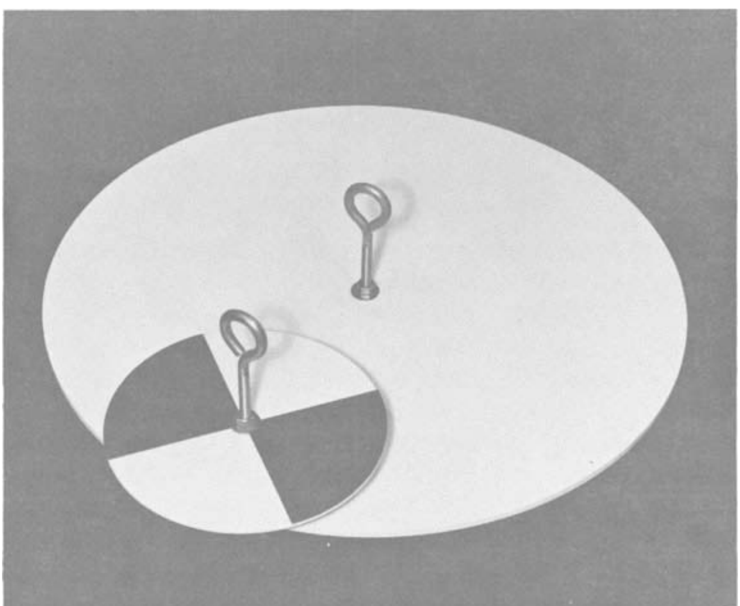
Some of these items are more relevant to pollution problems than others, and it is the ability to dissolve many different substances that we should expand on here.

One of the reasons for water's crucial importance is its ability to act as a solvent. A great many different substances, from soap to salt, from fertilizer to fallout, dissolve in water. This means that those substances are spread as the water that contains them spreads. When an animal drinks water, it also drinks the stuff dissolved in it. When a plant grows in water, it absorbs some of the dissolved materials as well as the water. Thus water is a kind of dispersal agent or carrier, distributing a huge number of different substances throughout almost every part of the ecosystem.

Many of the simplest substances that water dissolves are also the most influential ones in the ecosystem. For example, the salt-like chemicals in soil are easily dissolved in water and carried into the streams. Most of these substances form electrically charged particles in a water solution. In talking about these electrically charged particles, we can use the chemist's name for them — *ions*. Thus common salt (NaCl) in water exists mostly as sodium-ions (Na^+) and chloride-ions (Cl^-); and the phosphate in detergents, which has been blamed for some water pollution, forms phosphate-ions. Some of you will be aware of the distinction between hard and soft water, especially when you try to work up a lather with soap in hard water. The difference is due to the presence of certain metal ions, including calcium-ions and magnesium-ions.

Furthermore, water is an effective carrier of particles, even if they do not actually dissolve. Fine bits of soil, especially silt and clay, are carried in streams that are fed from flowing surface water. Small pieces of bark, leaves, insect wings, and pollen grains drift in water. Cells of bacteria, algae, and simple animals are suspended in water and are carried along with it. So, too, are other tiny particles, and all of these give the water containing them a cloudiness that is called *turbidity*.

A simple and effective method for estimating the turbidity of lakes and streams is widely used. The apparatus is a heavy piece of metal called a Secchi disc (see photograph). The disc is lowered into the water on a rope and viewed in the shade of a boat or bank. One notes the depth at which the disc first disappears from sight. Then the disc is slowly raised and the depth noted when the disc first reappears. The figures are averaged to give the accepted Secchi disc reading. The process should be repeated several times and the results averaged. The readings will vary with the time of day, the wave action, and the number of suspended particles in the water. Home-made Secchi discs



Secchi discs are used for estimating the clarity of water.

can be made by painting old pie plates in alternate black and white quarter segments, but unless these are the exact dimensions of the standard disc, the results obtained cannot be compared with those from standard discs.

Living things are influenced by the kinds and the quantities of the substances dissolved in the water they use. Some tropical fish fare badly in soft water. Water weeds and algae grow thickly in water containing dissolved nutrient ions such as phosphate, potassium, and nitrate. Cattle become sick if they drink from certain ponds. One of the critical qualities that dissolved ions give to water is acidity, and this quality is important enough to deserve a section of its own (Section 2.3). Another critical property of water is its ability to dissolve the important gases oxygen and carbon dioxide. Nearly all living things depend upon oxygen as part of their energy-release system, and so the life of most aquatic plants and animals is influenced by the amount of oxygen available in the water. Similarly, the green water plants, both the large weeds and the microscopic algae, require carbon dioxide for photosynthesis (Section 3.2). These plants are the primary producers in an aquatic ecosystem and the life of that ecosystem depends upon the supply of carbon dioxide dissolved in the water. Sections 2.5 and 2.6 are devoted to gases in water.

2.3 Detecting Acids and Bases

Humans have a patch on their tongues that is especially sensitive to the presence of acids. This means that we can taste acids in our foods. The tang of vinegar on potato chips is due in part to the fact that vinegar is an acid solution.

Perhaps our ability to taste acids makes it easier for us to accept the existence of acids than to accept the existence of anti-acids. But anti-acids are as common as acids and, when chemically strong, may be as destructive as acids. The chemist's word for anti-acid is "base" (or sometimes "alkali"). As you proceed with your study of water in the ecosystem, it is important to remember that a base is the opposite of an acid.

It is very difficult, if not impossible, to study water without also thinking about acids and bases. There is much evidence for believing that fresh water is not simply a stable collection of molecules represented by the formula H_2O (see Appendix). It appears that some of the water molecules fall apart into two fragments that can be identified in chemists' terms as H^+ (standing for "hydrogen-ion") and OH^- (standing for "hydroxyl-ion"). This process could be written

$$H_2O \rightarrow H^+ + OH^-$$

but it is important for you to realize that this chemical equation does *not* mean that all water molecules are being broken up into ions at any one time — only some are. There is evidence for thinking that the two ions may combine together to re-form water molecules:

$$H^+ + OH^- \rightarrow H_2O$$

The two reverse processes seem to go on at the same time in any pure water sample. This two-way activity is written thus:

$$H_2O \rightleftarrows H^+ + OH^-$$

and means that water molecules can fall apart and re-form. It also means that in a stable situation, in any period of time, about as many molecules form as fall apart.

You may have noticed that the ions bear equal but opposite electrical charges and that the water molecule itself appears to be neutral. The electrically active properties of the hydrogen-ions and the hydroxyl-ions are explored more fully in the Appendix.

By now you may be wondering just what all this has to do with acids and bases. The answer is an interesting one. Experiments show that the things we call acids all have an excess of hydrogen-ions. Acids supply hydrogen-ions to the watery solution and there are, therefore, more hydrogen-ions than hydroxyl-ions. In a similar way, bases supply hydroxyl-ions to the watery solution. A basic solution has more hydroxyl-ions than hydrogen-ions.

A number of questions now arise. If our account of hydrogen-ions and hydroxyl-ions is correct, what ought to happen when an acidic solution is mixed with a basic solution? Another way of posing the same question is to ask whether or not a solution can be acidic and basic at the same time. A second question is whether pure water is acidic or basic. You will be able to think of other questions to discuss with your teacher.

Chemists have devised a very useful scale for expressing how acidic or how basic a solution is. Some of you may already have had experience with the pH scale, which is a set of numbers, ranging from 0 to 14, expressing the degree of acidity. The lower the number on the scale, the more acidic the solution is. The higher the number on the scale, the more basic the solution is. In the middle, at pH7, a solution is neither acid nor base. To put it another way, one might say that pH7 is the place on the scale where a solution is equally acid and base. Generally a solution at pH7 is called "neutral" (Fig. 2:1).

The presence of acids can be detected by taste, but this method has some obvious drawbacks, and our tongues don't work well at detecting bases. Fortunately, chemists have discovered a number of substances that change colour when placed in solutions of different acidity. Some of the substances occur naturally in plants; others are dyes extracted from coal products. An easy one to experiment with is the dye obtained by boiling a few red cabbage leaves in water. The purple juice of the red cabbage can be tested with common acids such as vinegar, soda water (carbonic acid), and boric acid, or with common bases such as baking soda, magnesia, and ammonia. Figure 2:1 shows the pH scale with some common substances and the colours found in widely used dyes. When you are equipped with a bottle of pH-indicating dye and a set of known colour standards, it is a fairly simple matter to estimate the acidity (or basicity) of any water sample. An easier, but less precise, method involves the use of a paper strip containing pH indicators in dry form. The solution being tested is applied to a bit of this paper, and the resulting colour is compared with the standards provided.

There are three further points. First, as the pH scale and the use of indicators is best understood through practice, a laboratory activity is described below. Second, you might ask who set up the standards? How was it done? How do we know they are right? These questions are left for you to pursue on your own or with your teacher. Third, the breakdown of water into hydrogen-ions and hydroxyl-ions is more complicated than shown here, although it wouldn't be helpful in measuring the acidity of water to go into that complication. Those of you who study further chemistry will become acquainted with the details of this process.

Laboratory Activity 2-1
Detecting acids and bases

It will be helpful to compare the colours of various indicators when they are put into different solutions. In addition to the cabbage juice, one could also use indicators such as bromthymol blue, phenol red, and indigo carmine.

What colour is produced when a drop or two of indicator solution is placed into any one of a variety of sample solutions? What is the pH of the various solutions as measured by Hydrion paper? The laboratory results can be recorded in a table like the one that follows.

Table of Results — detecting acids and bases

Solution tested	*pH as shown by Hydrion paper*	*Colour of Indicators*		
		Brom.-Blue	*Phen.-Red*	*Ind.-Car.*
Cream soda				
Dilute hydrochloric acid				
Vinegar				
Salt solution				
Baking soda solution				
Household detergent				
Dilute ammonium hydroxide				
(Make up solutions of your own and test them.)				

In some schools, you may be able to check your results against an electrical pH meter. In other cases, it will be easier to check findings against the common pH values and indicator colours given in chemistry books.

Substances		pH	Indicator Colours: Phenol phthalein	Red Cabbage Water	Bromthymol Blue	Phenol Red	Indigo Carmine
	increasingly more H^+ than OH^- in solution	1	colourless ↓		yellow ↓		
		2					
Vinegar ▶		3					
		4					
Water from good blueberry soil ▶		5			↓ becomes greenish		
		6	↓		↓		
Fresh distilled water ▶		7	becomes pink		green ↓ becomes		
	increasingly more OH^- than H^+ in solution	8	then		bluish ↓		
		9	red		blue		
Milk of magnesia ▶		10					
		11					
Limewater ▶		12					
		13	↓		↓		

Figure 2:1 The pH scale showing the approximate values of some common substances, the relative proportions of H^+ and OH^-, and the colours of two indicators. You may wish to make a chart of your own to show the results of your lab work with the other indicators.

Once prepared with some experience in detecting acids and bases, one should attempt to measure the pH of various water supplies. Some of the many sources that can be tested are tap water, aquarium water, water from nearby ponds, ditches, creeks, or rivers, cistern water, and rain water. If a field trip is planned, take pH indicators along to test the various kinds of water found. One might discover, for example, if the pH of water in a river near by is the same upstream as it is downstream from a factory or dairy farm on its bank.

2.4 How Much?

It is one thing to know whether a solution is acidic, neutral, or basic; it is another thing to tell *how strongly* acidic or basic the solution is on the pH scale, and it is quite another thing again to know *how much* acid or base is present in the solution.

If the chemical reaction described in Section 2.3

$$\underset{\text{(acid)}}{H^+} + \underset{\text{(base)}}{OH^-} \rightarrow \underset{\text{(water)}}{H_2O}$$

is correct, then two things follow. First, acids and bases ought to have a neutralizing effect on each other. Second, for every extra hydrogen-ion that there is in an acid, neutralization should require the addition of one extra hydroxyl-ion. Sixteen million hydrogen-ions should just neutralize the very same number of hydroxyl-ions.

$$393\,H^+ + 393\,OH^- \rightarrow 393\,H_2O$$

Thus, if we can devise some way of measuring (or counting) the number of ions of a known solution required to neutralize an unknown solution, we will be able to estimate how much acid (or base) was present in the unknown one.

Several methods of answering the question "How much acid (or base) is required?" have already been worked out. They are called *titrations*. In one method of titration, a carefully measured volume of an unknown solution is placed in a beaker, together with a few drops of an appropriate indicator solution. Then just enough solution of known acid (or base) is added to use up all of the base (or acid) present in the unknown one. In many cases the final mixture will be neutral (pH7), as shown by the indicator colour. In some special situations which should not concern us here, the final pH may not be 7. It depends on the particular acids and bases being used.

You will probably realize by now that if we measured out twice as large a volume of unknown solution it would take twice as large a volume of a known standard solution to use up the unknown's base (or acid). It further stands to reason that the doubled volume of unknown solution would also be neutralized by the original volume of standard solution if only the standard were twice as strong. These possibilities mean that a person doing a titration must keep very accurate records of both the kinds of solutions and the volumes of the solutions that he uses. The technique of titration and the chemical arithmetic needed to understand the method of calculation are somewhat isolated from our main task of understanding the importance of water in the ecosystem. Complete titration experiments are found in the Appendix.

2.5 Gases in Water

It has been suggested (Section 2.2) that the ability of water to carry dissolved gases is vitally important to living things. The kinds of plants and animals, and the numbers of each kind living in a stream, depend in large part upon the amounts of oxygen and carbon dioxide available.

You have probably already had some experiences with gases dissolved in water. The carbon dioxide that gives "soda pop" its bubbles is familiar to us all, and we are aware of a number of the conditions, such as temperature and pressure, that influence the amount of a gas that will dissolve.

While thinking about the importance of water in the ecosystem, it is appropriate to investigate the ability of water to hold the gases important to living things. It will also be necessary to have ways of checking the amount of available oxygen in natural waters and the possible effects of pollutants.

Laboratory Activity 2-2
How do various gases affect the acid-base indicators?

It is not hard to prepare a variety of gas solutions in the school laboratory. For example, freshly distilled water that has been reheated and then cooled in a brim-full, covered container will be very nearly gas-free. Some of that water can then be made to dissolve the gases of the air if air from an aquarium air pump is bubbled through the sample. One can make another portion of distilled water dissolve carbon dioxide by bubbling in that gas from a carbon dioxide generator or lecture-bottle cylinder. A few small chunks of dry ice, which is frozen CO_2, can also be used as a source of carbon dioxide. Similarly, oxygen from a cylinder (or laboratory generator) can be bubbled through a water sample, and other gases, such as propane, nitrogen, helium, or acetylene, can also be tried.

CAUTION: Some pure gases are chemically very active. A few are flammable. Be sure to check the safety procedures with your teacher.

Your experience with soft drinks should remind you that gas solutions will be easier to make if cold water is used. It might help to chill the beakers and water in containers of crushed ice.

What colours are produced when a drop or two of various indicators are placed in the different gas solutions? Prepare a table of results showing the gas dissolved, the colour produced by (a) bromthymol blue, (b) indigo carmine, and (c) phenol red, and also the pH, as shown by pH test paper.

Some students should repeat the experiment at several very different temperatures, to see if water temperature really has any effect on the pH of gas solutions.

You will probably have learned some things from Laboratory Activity 2-2 that are relevant to environmental pollution. One thing to look for is the connection between water temperature and the amount of oxygen held in solution. You can then begin to guess why plants and animals with high oxygen demands do not live in warmer water, and why the addition of waste industrial heat to lakes and streams is such a serious form of pollution. (See Section 4.2 for further work on fish requirements for dissolved oxygen and Section 4.8 on thermal pollution.) Another fact you should note is that acid-base indicators show only the *presence of acids and bases*. They do not give information about the *amounts of particular gases* in water. Furthermore, many substances other than gases affect the pH of a solution.

In other words, the indicators cannot tell you what substance or group of substances is making a water sample acidic or basic. This means that indicators are of very limited usefulness in gas studies. You should also realize that all of the gas work we do, we do in an atmosphere of air. Air gets at everything, and the oxygen, nitrogen, and other gases of the air in the laboratory can influence the results of experiments. Can you work out ways to reduce this problem?

Laboratory Activity 2-3
Comparing oxygen levels in different water samples

There is a method of accurately measuring the quantity of oxygen dissolved in water. The method requires a reasonable amount of skilled technique and is described in the Appendix. In this laboratory activity, however, we will use a cruder, less precise, but easier version of the same test.

Use water samples of equal volume, somewhere between 20 to 30 ml each. Put five drops of concentrated sodium hydroxide solution into each sample. Put five drops of concentrated manganese (manganous) sulphate solution into each sample. A cloudy, whitish solid will form which will then turn any colour from a yellowish shade to brownish black. The more oxygen there is available, the darker the colour will be. This method permits comparison of various water samples. It will tell which ones have more oxygen, which have less, or which have about the same amounts, but *it will not tell how much* oxygen is in any sample.

There are difficulties in this experimental method. The main one is caused by the fact that every time you unplug the test tubes or water-sample bottles, you let in air, and air is nearly 20 per cent oxygen by volume. It will help to exclude some of the air if the bottles or tubes you use are very nearly full. You will also see that pouring your collected water samples from vessel to vessel, trapping air bubbles, or hard shaking will all tend to spoil the results. If you can get BOD bottles (see Question 3 of Chapter 3) you can reduce these difficulties.

A second type of difficulty arises when students use the same droppers for the two test solutions. You can spoil your results in this way. Don't forget, either, that *the solutions of sodium hydroxide and manganese (-ous) sulphate are caustic. Keep them off your clothes and skin.*

Laboratory Activity 2-4
How does sulphur dioxide affect acid-base balance?

Sulphur dioxide is one of the commonest air pollutants, and one of the worst. It is common because many fuels (such as coal) contain sulphur, and burning the fuel releases the sulphur to form sulphur dioxide gas. The idea of this experiment is to find out why sulphur dioxide gas is undesirable and unpleasant in the air.

There are several ways of making the gas. The easiest is to heat a lump of sulphur, about the size of a small green pea, in a deflagrating spoon or in a holder formed from aluminum foil. The sulphur will eventually burn quietly and the spoon or foil can be lowered into a gas bottle for a minute or two. Repeat the operation with a second gas bottle and even a third if your supply of sulphur holds out. Cover the bottles to prevent loss of the gas. Then pour water into the bottles to a depth of about one centimetre and shake well. (The water may be placed in the bottles earlier, if you wish.) Use pH test paper and appropriate indicator solutions to check the pH of the water.

What is the evidence for believing that sulphur dioxide dissolves easily in water?

What pH is the solution and how can you be sure the original water wasn't that same pH when you first poured it into the gas bottle?

How could you measure the exact amount of acidity or basicity in the solutions?

CAUTION: The lining of your breathing passages is moist. Sulphur dioxide in solution has a distinctly unpleasant effect on your body, even in small quantities. The effects of large quantities are dangerous. The surface of your eyes is also moist.

A well-ventilated area is required for this laboratory activity.

Now that you have done this experiment, you have joined the ranks of those who are guilty of producing sulphur dioxide pollution. If you took too large a lump of sulphur, how did you get rid of the burning excess? If you used a well-ventilated room, weren't you simply spreading the pollutant around? How are you going to get rid of the water solution of sulphur dioxide in the gas bottles? There is a way of neutralizing the solution and forming a solid. But what will you do with the solid?

2.6 Life in Polluted Water

There is evidence that suggests that the kinds of plants and animals found in a lake or stream are related to the condition of the water. It appears that water containing large amounts of dissolved and suspended material encourages the growth of different kinds of organisms more than does water containing less dissolved and suspended material.

One example of this relationship is found when one studies the algae growing in the water. (Algae are simple plants, usually only a few cells in size, such as the green fuzz that grows on the walls of fish bowls.) Water that is comparatively "clean"—that is, having few dissolved substances—contains more dia-

Numbers of species of algae in polluted and unpolluted water.

Type of algae	*Polluted*	*Unpolluted*
Blue-green	15	6
Green (non-swimming)	8	12
Diatoms	7	12
Red	0	3

toms and green algae and fewer members of the blue-green algae group. Water that is richer in dissolved substances — that is, "dirty" — contains more blue-green algae and fewer members of the diatoms and green algae groups. The table shows some typical numbers of the various types of algae in different kinds of water.

Thus, by collecting and identifying the algae in a given body of water, one can form an impression of its condition.

Another example of the connection between water quality and the organisms that grow in it is the case of the aquatic worms and larvae. Complete studies on such animals have not yet been

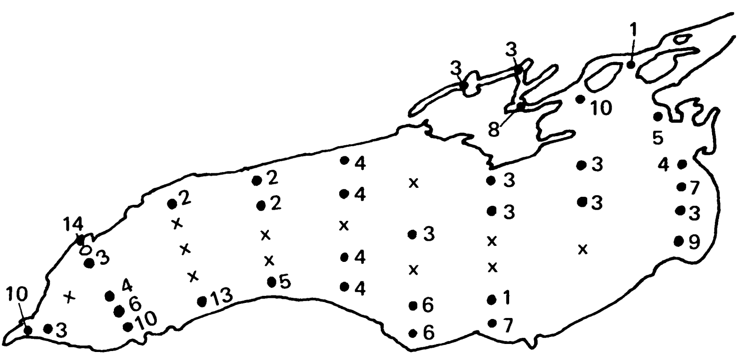


Figure 2:2 Map of Lake Ontario showing the distribution of sludge worms reported in 1968. The numbers indicate the approximate relative abundance of the animals. A small x indicates a sampling station where no worms were found.

done, but very recent research results show that the sludge worm (a relative of the earthworm, technically called *Tubifex*) and the blood worm (an insect larva called *Chironomus*) may be indicators of pollution.

Samples of bottom mud were taken from Lake Ontario in a pattern which evenly covered the entire lake. Figure 2:2 shows the places where sludge worms were found. Many sampling stations are not shown on the map because no sludge worms were found there. What possible explanations could account for the distribution of the sludge worms?

2.7 Other Possibilities

We have explored a few aspects of the importance of water in the ecosystem. The emphasis has been on the acid-base balance and on the role of water as a solvent for gases. There are, of course, a great many other dissolved substances that are of environmental significance. Some of these are described in other chapters; some are mentioned in the questions that follow; and some are left for you to explore on your own.

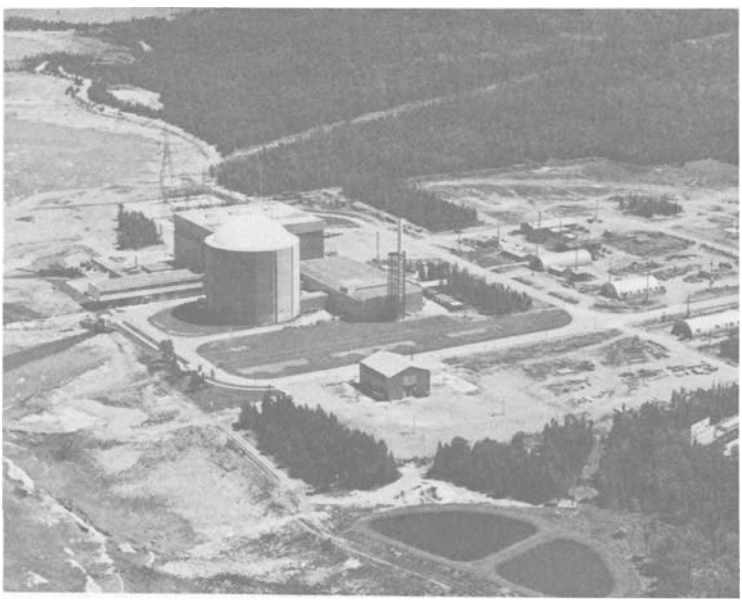
There is much that you can learn about pollution without having a deep understanding of the chemistry of water. However, the more insight into water chemistry you have, the further you can go with pollution studies. The Appendix offers a slightly more detailed study of the nature of water.

Questions

1. Six large pickle jars (about 1-gallon size) are filled with water from a nearby pond. The jars are supplied with varying amounts of commercial garden fertilizer and left to stand in a sunny window.
   (a) Which develops the thickest green growth?
   Which develops the least growth?
   (b) Which jar will support the largest number of water fleas

(Daphnia) or of mosquito larvae?
(c) What possible explanations can you offer for the differences in plant growth between the various jars?
(d) Here is a word that you should know: *eutrophication.* Find out what it means in the normal development of a lake or pond. How can the idea be applied to the six pickle jars of pond water? What does it mean in pollution studies?

2. You want to make a sample of water hold as much dissolved oxygen as possible.
(a) Which of the following items might you find useful: an egg beater, ice cubes, a kitchen blender, an electric kettle, aquarium air stone, hydrogen peroxide?
(b) What would you do to make the strongest possible solution of oxygen in water?

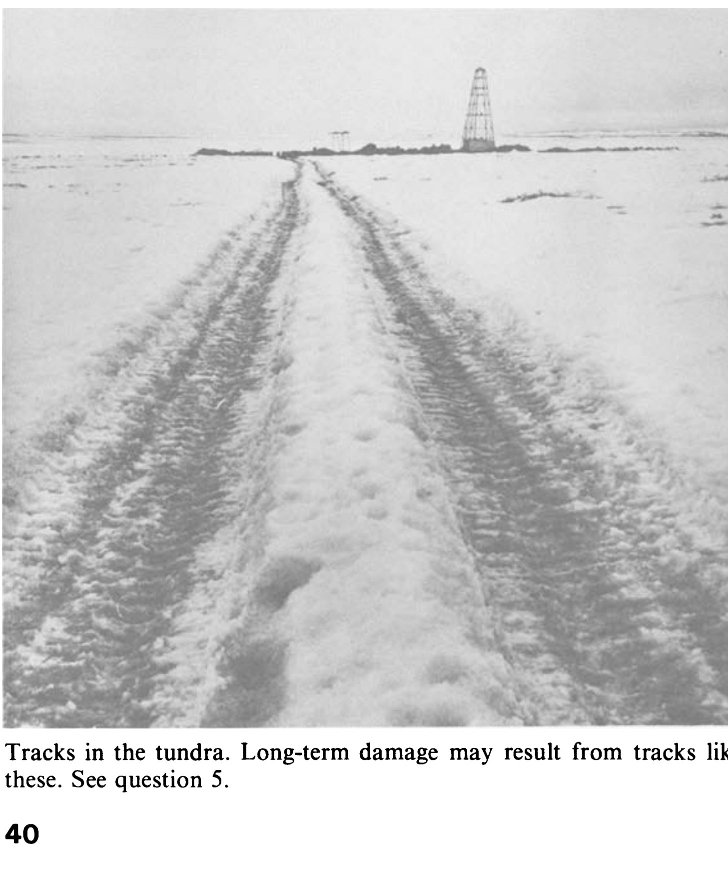


The Douglas Point Nuclear Power Station on Lake Huron. The nuclear reactor at this station releases heat energy for conversion to electricity. Compare the environmental effects of this type of electric generator with the environmental effects of generators driven by dammed-up water and by the burning of fossil fuels such as coal and oil.

3. In what respects is an arctic tundra ecosystem similar to a desert ecosystem?

4. Find out about "winter-kill" in lakes (What is it? What causes it?). How might the extensive use of snowmobiles on lake surfaces affect winter-kill?

5. Tracked snow vehicles are a great means of transport in the Arctic. But, to the distress of some people, these vehicles have left trails of damaged tundra that have yet to return to the original condition, though the trails may be some years old.
   (a) How is the damage done?
   (b) Why can the tundra not repair itself?
   (c) List eight or ten reasons for calling the Arctic "a fragile environment".



Tracks in the tundra. Long-term damage may result from tracks like these. See question 5.

6. The advance publicity for a new cement plant to be built near Bath, Ontario, claimed that the plant would be pollution-free. It was stated that the water taken from Lake Ontario for cooling purposes would not be returned to the lake. Instead, the warm water would be evaporated. What is your opinion of this method of preventing thermal pollution of the lake?

7. Figure 2:3 is a sketch map of parts of a lake and surrounding shore. Secchi disc readings were made at the points indicated at the same time of day and under the same surface conditions. The table below gives average readings at the various places.

Station	A	B	C	D	E
Reading (in metres)	4.0	2.5	2.2	4.8	5.1

(a) Which bay has the clearest water?
(b) What explanations are there for the differences in results obtained at the different stations?

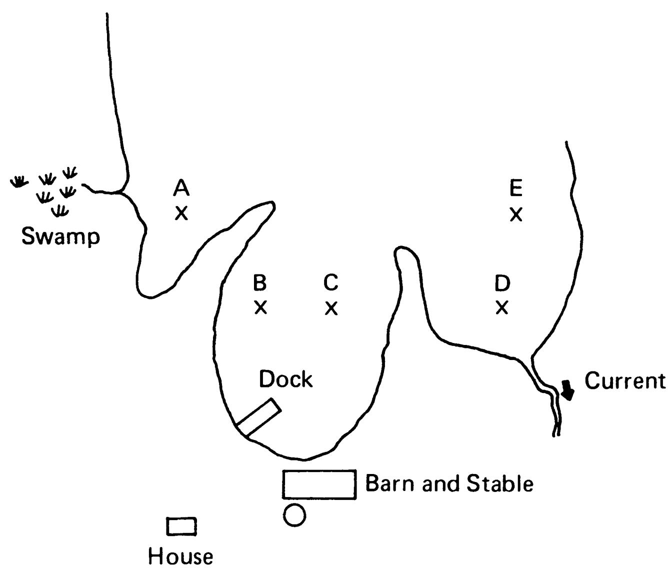


Figure 2:3

CHAPTER THREE

Producers and Decomposers

3.1 Gases Coming and Going

"Plants use up carbon dioxide and give off oxygen. Animals use up oxygen and give off carbon dioxide." These statements describe a very simple and commonly held belief about the balance of gases in the ecosystem. Experiments, however, suggest that the processes involved are extremely complicated, and a careful review of Chapter 1 and the accompanying figures will emphasize this.

An ecosystem is an active, shifting system rather than a stationary, changeless one. Understanding the dynamic nature of an ecosystem requires, among other things, that one know something about the exchange of gases between parts of the ecosystem. Let us consider how producers and decomposers react with each other as oxygen and carbon dioxide are released or used. (General relationships between producers and decomposers are given in Figs. 1:2 and 1:6.)

3.2 The Producers

It would be reasonable to ask what a producer does to deserve its name. One answer is that the materials produced are more

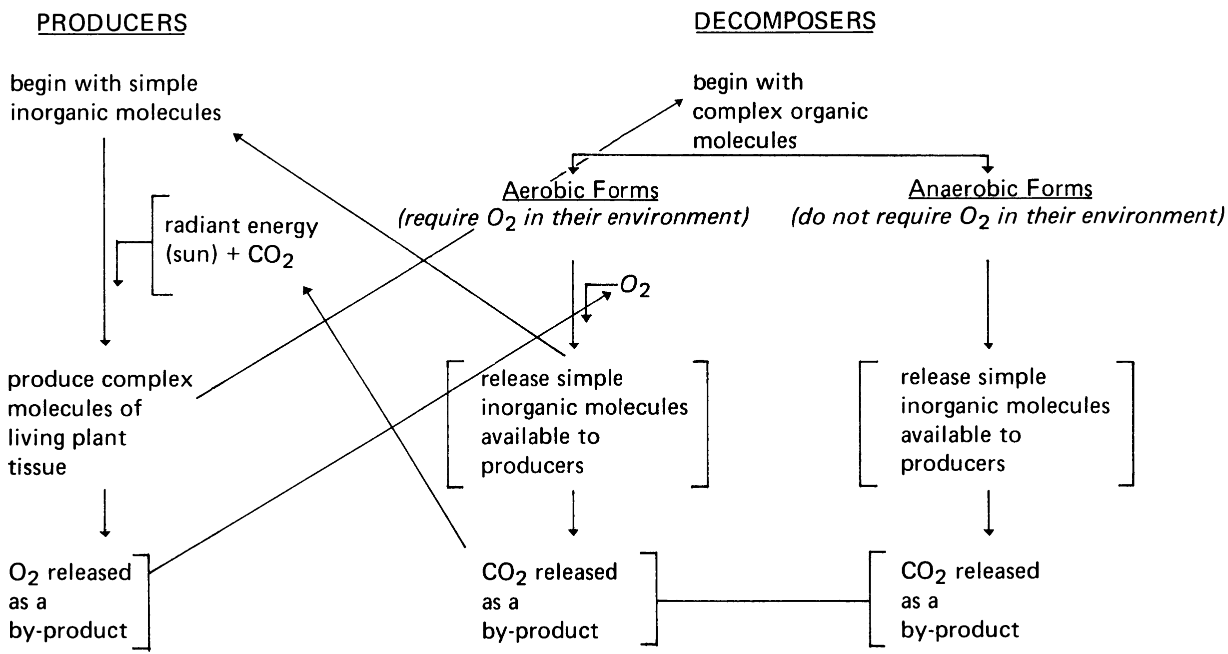


Figure 3:1 The interdependence of producers and consumers. In this simplified diagram, note how materials released as by-products by one group of organisms are taken up by members of the other group.

complex than the raw materials used up, and, generally speaking, producers do use up relatively simple chemicals (such as carbon dioxide and ions) to form more complicated materials such as fats, proteins, and carbohydrates.

Consumers and decomposers also produce their own complex chemicals, but they must have other, even more complicated ones, rather than simple ones, to begin with. Thus it may be said, with considerable confidence, that producers use simple substances, whereas decomposers and consumers use complex ones.

Energy is needed in the construction of any large, complex substance from simpler components. Producers have a means of trapping some of the light energy from the sun in such a way that the chemical construction of larger molecules can be started (Figs. 1:6, 3:1).

All of these ideas are summed up in the familiar words: "Producers carry on photosynthesis." Recall, or review, what you have previously learned about photosynthesis as you do the following experiment.

Laboratory Activity 3-1
What effects has a producer on the amounts of oxygen and carbon dioxide in its environment?

If a producer is an organism that removes simple substances from its surroundings and uses them to make complex ones, then it should be possible to set up a system in which these changes can be observed. One important change to watch for is the loss of simple substances such as carbon dioxide and ions from the surroundings of the producer. Another would be an increase in the amount of starch, protein, or fat in the body of the producer. Because we have been giving special attention to the essential gases — oxygen and carbon dioxide — let us see what happens to those gases in a water solution containing an active producer.

The idea of the experiment is to keep pieces of healthy water plant in samples of water for a few hours and then to check for any change in the amounts of carbon dioxide and oxygen present in the water. The commonest plant used is Elodea (*Anarchis*),

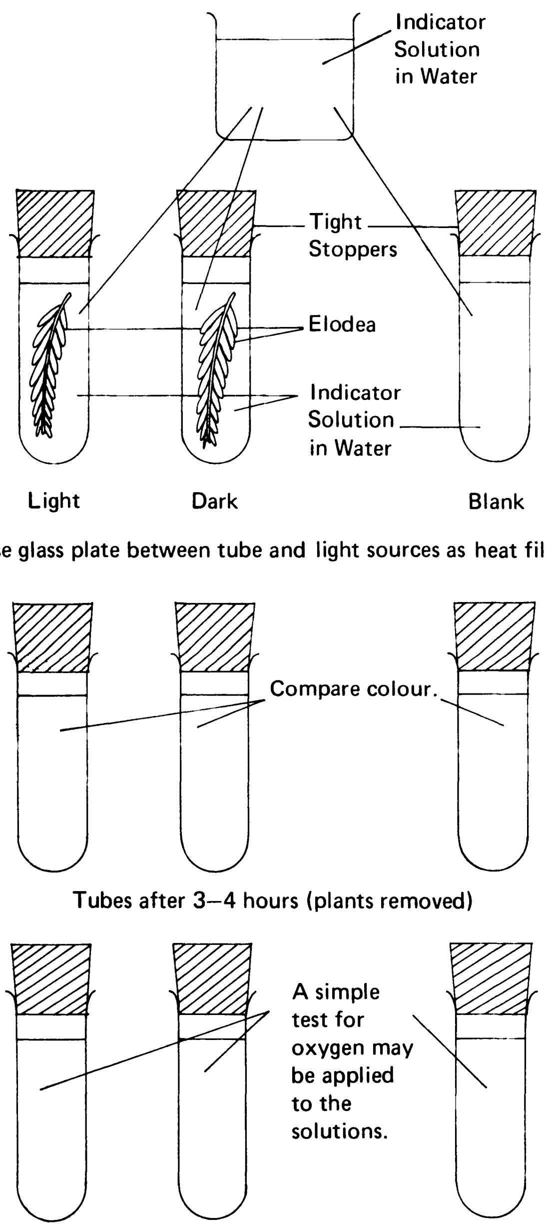


Figure 3:2 The apparatus for determining the effect of a producer on the carbon dioxide content and oxygen content of its environment.

but any vigorous, actively growing water plant will do. Some investigators have used a variety of aquarium plants, or algae, for this experiment. Indeed, the experiment can also be done in air with leaves from ordinary land plants. (See Figs. 3:2 and 3:5.)

Some freshly distilled water, tinted with bromthymol blue indicator solution, may be used. (See also the indicator solution referred to in Laboratory Activity 3-2.) It helps to blow your breath through the solution until the colour is distinctly yellowish green. The solution can then be set up in the three tubes, as shown in Figure 3:2. You will recall that if the indicator gets more yellow, it means an increase in acidity, which could be caused by an increase in dissolved carbon dioxide. Conversely, if the indicator turns more blue, it means an increase in basicity, which could be due to a decrease in dissolved carbon dioxide.

If you want to compare the oxygen content of the tubes, you can apply a simple test to the water in each. Laboratory Activity 2-3 describes one such chemical test. The Appendix gives a much more detailed and precise method of measuring dissolved oxygen.

Why is it important to include a tube without a plant in this experiment?

What do producers do in the dark that contradicts the opening quotation in Section 3.1?

The results of many experiments suggest that plants behave like producers (that is, they take up carbon dioxide) under certain conditions, and behave like decomposers, or consumers (that is, they take up oxygen) under others.

The presence of light is the one variable investigated here, but there are several other requirements well known to plant scientists. How can producers grow if each night they break down the material produced the previous day? Put another way, what is the balance between the amount of carbon dioxide used by a producer at one time and the amount of oxygen used at another time? Precise answers to these questions are difficult to get because most plants use oxygen constantly, whether or not they are also taking in carbon dioxide. Furthermore, the speed at which oxygen is used changes a great deal during the course of a day.

Study Figures 3:3 and 3:4. If you are interested in these prob-

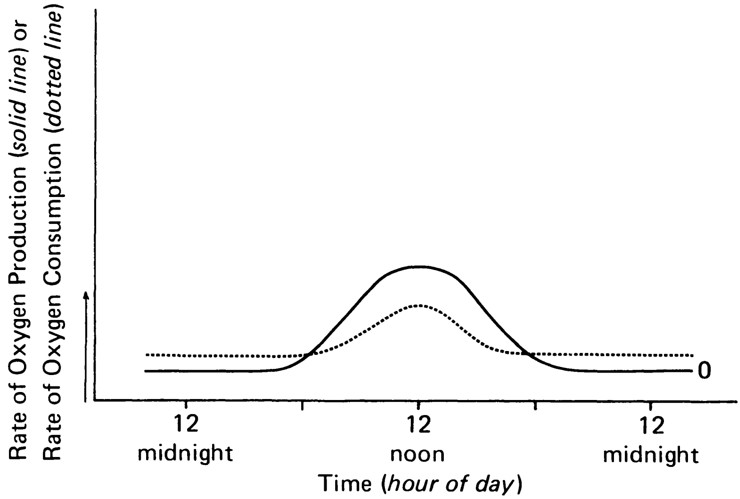


Figure 3:3 A generalized graph of oxygen production and oxygen consumption by a green plant at various hours of the day. At what times are oxygen use and oxygen production equal? In this particular graph, roughly how much more oxygen does the plant give off than it uses up?

lems, you can follow them up through a variety of sources. It will have to be enough here to say that, in general terms, producers use up more carbon dioxide than they do oxygen, and that they give off more oxygen during the daylight hours than they use up during a 24-hour day. If these points are true, it should be possible to seal a plant in a tube of indicator solution and watch it use up carbon dioxide faster (through photosynthesis) than it can give off carbon dioxide (through respiration).

Laboratory Activity 3-2
How long does it take a plant to use up the carbon dioxide it gave off overnight?

If you seal a plant in a suitable chamber containing a special bicarbonate indicator solution (see Appendix, page 110), you can measure the length of time it takes for the plant to take in all of the carbon dioxide it gave off overnight. Scientists call this the *compensation period.*

Seal a healthy sprig of Elodea in a tube filled with the in-

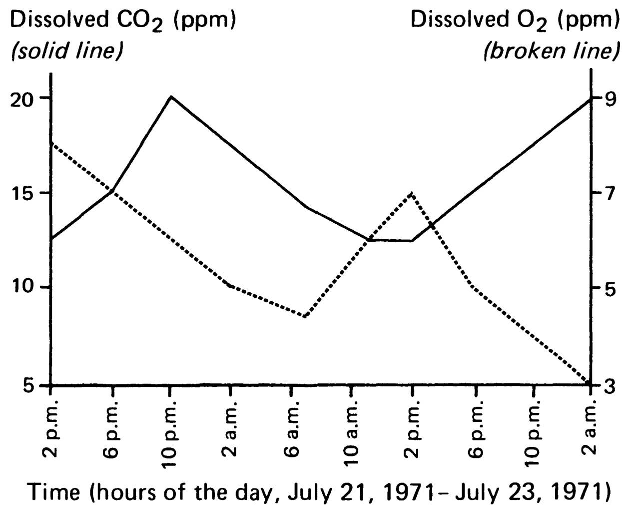


Figure 3:4 Graph showing the content of dissolved oxygen and carbon dioxide in samples of pond water over a 36-hour period in July 1971. The measurements were made by R. B. Hardy. What factors might explain the changes in the amounts of the gases dissolved in the water? Why do the two curves tend to run out of step with each other?

dicator solution (Fig. 3:5). Do this near the end of the day and leave it *in the dark* until morning. The indicator will have changed colour overnight, according to the amount of carbon dioxide given off by the plant in respiration.

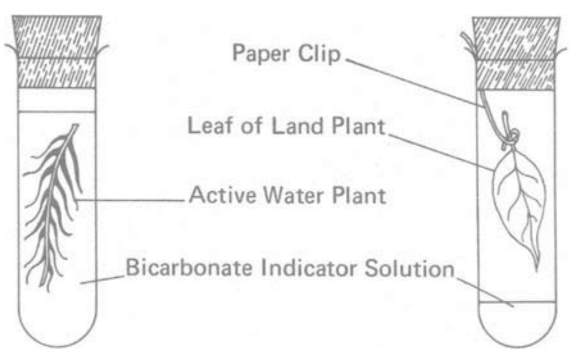


Figure 3:5 The indicator changes colour in the dark overnight owing, presumably, to the production of carbon dioxide. How long does it take to return to the original colour in the light? How can you remember what the original colour was?

Now, expose the plant to bright light, keeping the temperature about the same as before, and record the length of time required for the indicator to return to its original colour. Compare that length of time with length of the overnight period.

The point of these experiments is to help you picture the influence that producers have on the balance of gases in the ecosystem. That influence depends upon the conditions of life for the plant. If the producers can photosynthesize vigorously, they will have one kind of effect on the oxygen–carbon dioxide balance. If the conditions for photosynthesis are poor, the producers may have little effect upon the balance of gases. When environmental conditions prevent or inhibit photosynthesis, producers have another kind of influence on oxygen and carbon dioxide levels. (Refer back to Chapter 2, Question 4.)

3.3 Photosynthesis and Net Oxygen Gain

While not essential to the development of the theme of environmental pollution and its consequences, it is still worth noting here that plant scientists have invented much more accurate methods than those just discussed for measuring net oxgyen production by a living plant.

Merely knowing that there *is* a net gain may be of some interest, but to use this information in the detailed study of an ecosystem, it is necessary to know, as precisely as possible, the *amount* of this gain.

If you wish to investigate the procedures for such measurements, refer to the section "Measuring Primary Productivity" in the Appendix.

3.4 The Decomposers

A very general way of describing a decomposer's action is to say that it reverses the activities of the producer. This, of course, is an oversimplification because producers perform two "contrary" processes: respiration goes on continuously at relatively slow rates, while photosynthesis proceeds at relatively faster rates when conditions of light, temperature, and other environmental factors are suitable.

On the other hand, the *decomposers never do photosynthesize, but do respire continuously* at rates which vary with conditions.

Thus, while producers have the over-all effect of decreasing the world's free carbon dioxide supply and increasing the world's available oxygen, decomposers have an opposite action on the gas levels.

Laboratory Activity 3-3
How much carbon dioxide do decomposers release?

A very simple estimate of carbon dioxide production by decomposers can be obtained by placing a sample of decomposer in a closed system with a pH indicator at or near its colour for pH8. The time required for the indicator to change through the colours for pH7, pH6, etc., would give an estimate of carbon dioxide production. What assumption is being made whenever an acid-base indicator is used to estimate carbon dioxide?

You will find the bicarbonate indicator used in Laboratory Activity 3-2 most responsive to the pH changes caused by differences in the amount of available carbon dioxide.

Any one of several decomposers will do. Try mouldy bread, rotting boiled potatoes, or a yeast culture. Figure 3:6B suggests one way of arranging the apparatus so that a constant pressure can be maintained in the system. (This is one of the difficulties in experiments of this kind.) The solubility of gases in the indicator solution is influenced by the pressure and temperature of the system, and both should be kept constant.

A modification of the experiment is to measure the *volume* of carbon dioxide gas generated by yeast. A yeast culture is prepared by stirring one package of yeast into 1000 ml of water at room temperature with 200 gm of table sugar in solution. The yeast culture is poured into fermentation tubes (Fig. 3:7) and,

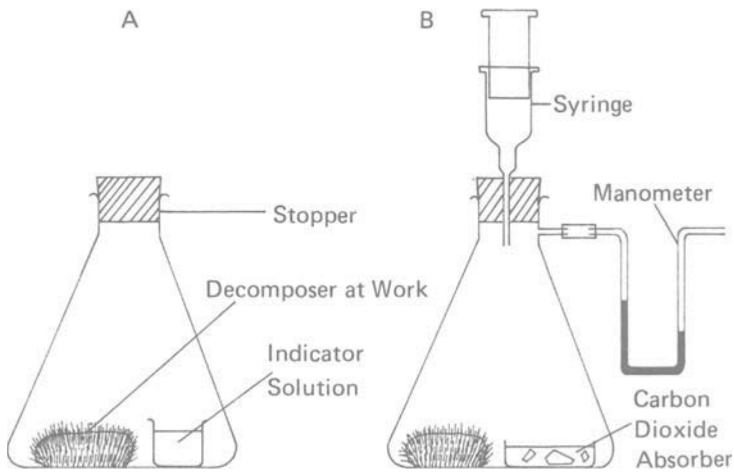


Figure 3:6 A. Testing for the presence of CO_2. B. If the indicator solution were replaced by a CO_2 absorber, such as potassium hydroxide, and if the flask were fitted with a simple manometer and syringe, the syringe could be used to measure oxygen consumption. How could this be done?

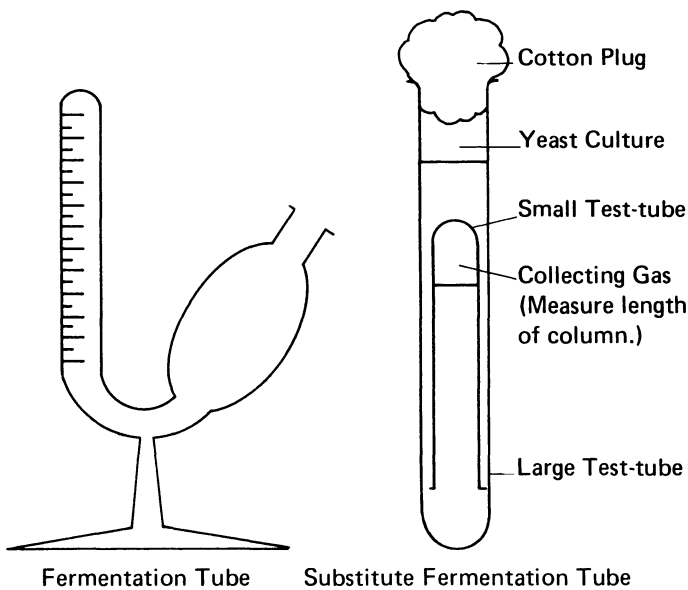


Figure 3:7 Apparatus for measuring the rate of carbon dioxide production of yeast. The one on the left is the commercial fermentation tube; on the right is a suggested alternative.

as the yeast decomposes the sugar, the volume of gas appearing in the tube is recorded. One should record the time of each volume reading, so that results can then be displayed on a graph. Figure 3:7 also illustrates an apparatus that can be used instead of the fermentation tube.

Some decomposers, such as baker's yeast, brewer's yeast, and certain bacteria, have a chemical action on their surroundings that results in the production of carbon dioxide without using up oxygen. They are called *anaerobic* as distinct from aerobic organisms that require oxygen. Anaerobic organisms live actively in the absence of oxygen. Indeed, oxygen may actually interfere with their life processes. Decomposers of this kind are easiest to work with, in experiments such as those of Laboratory Activity 3-3, because there need be no concern about one gas being used up almost as fast as another is given off.

It should be emphasized that there are a vast number of decomposers that must have oxygen to live. Decomposers of this kind are vitally important in the ecosystem and, while harder to study experimentally, should nevertheless be considered.

Laboratory Activity 3-4
What are the decomposers around us?

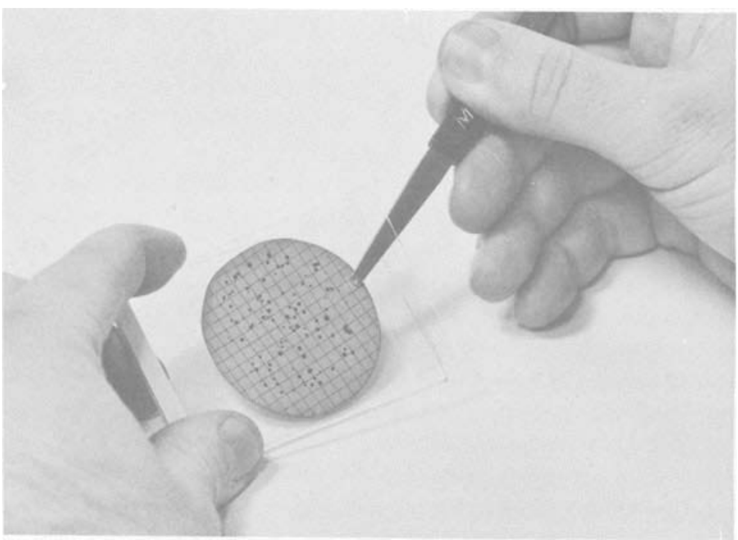
Many different kinds of decomposers will grow rapidly, either in a watery broth or on a gelatin surface. It is only necessary that the culture medium contain an adequate supply of the complex nutrient molecules essential to the life of the decomposer. If the decomposer requires oxygen, air must be available. It will, of course, be desirable to keep out poisonous substances such as chlorine and disinfectants, which would prevent or inhibit growth.

The commonest culture medium used in the laboratory for growing colonies of bacterial decomposers is called nutrient agar. It may be prepared in sterilized flat culture plates from any one of a variety of standard mixtures available from a laboratory supply company. If these plates are opened to the air for various time intervals, then covered again and left to incubate at room temperature, it will be possible for you to count the number of bacteria that fell on the plate during exposure. This works because each bacterial cell thus captured will grow by cell division into a visible colony, containing millions of cells. It may help in counting the number of colonies to draw a grid of squares on the bottom of the culture dish.

With this technique you can compare the number of bacteria in the air in different rooms, in different buildings, and in different locations outside.

Drawing conclusions from this type of experiment presents certain difficulties. Consider these questions: After a growth appears on one of your plates, how can you tell that it is due to bacteria from the air and is not something that would have grown there anyway? How do you know that all of the bacteria falling on the plate were able to grow in the medium and conditions provided?

A very effective method of detecting and counting bacteria in a volume of air or water has been worked out by the Millipore Corporation. If your school has a Millipore kit, it could be used instead of the experiment described above.



Millipore filter, showing colonies of bacteria, being placed in a permanent mount. Note the squared surface of the filter, which makes it easier to count the numbers of colonies.

Now that you have formed some ideas about the occurrence of bacteria in the air, it will be possible to adapt the techniques discussed in Laboratory Activity 3-4 to test samples of water and soil.

Using the living decomposers you have growing in culture plates, you will have an opportunity to find out what conditions are best for their rapid growth. Remember that decomposers have an important part to play in the cycling of substances through the ecosystem. Perhaps, if we can learn how best to encourage decomposer action, we can speed up the breakdown of pollutants.

Laboratory Activity 3-5
What conditions help decomposers to grow faster?

At the beginning of this inquiry, your class will be divided into a number of teams, each of which will be provided with a sample of bacteria from a single stock culture prepared earlier from one of the colonies grown as part of Laboratory Activity 3-4.

Your teams will also need to agree on a common method of measuring growth. Colony diameter is one possibility, and another is the increase in murkiness of a broth, as illustrated in Figure 3:8. It will also be necessary to set a time limit.

The idea is for different teams to try a variety of conditions in the attempt to discover which ones have an effect on the growth rates of the decomposer. Your previous science training will have taught you the importance of keeping full, accurate, and readable records of the various things you try. Some of the things worth attempting are: changing the concentration of nutrients, adding (or removing) salt from the culture medium, keeping the cultures at higher or lower temperatures, using tighter (or looser) covers, and changing pH.

You will undoubtedly think of other possible variables, and ways of measuring their effects, as the study proceeds. Ordinary canned consommé or beef bouillon makes an excellent broth medium. Decomposers grow readily in it and the concentration

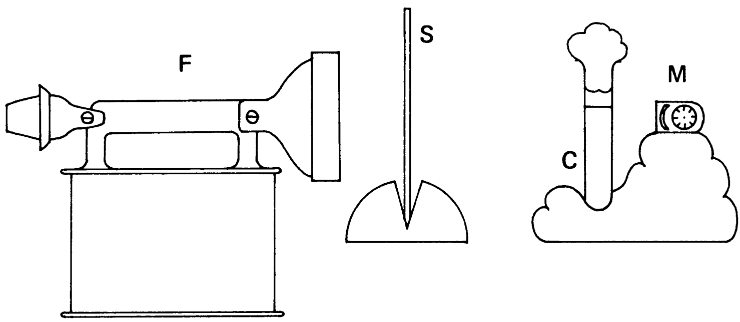


Figure 3:8 An apparatus to estimate the growth of bacteria in broth culture. *F* is a flashlight. *S* is a piece of cardboard with a narrow vertical slit cut in it. *C* is the culture tube containing beef bouillon and a decomposer. *M* is a photographic exposure meter. Some of the apparatus is supported in lumps of plasticine. The light meter detects the amount of light penetrating the culture. It is possible to compare the bacterial growth with control tubes by comparing the readings on the meter. *Warning*: 1. Simple photographic meters do not give readings that are directly proportional to light intensity. 2. It is important to keep the spacing between the parts of the apparatus the same at all times.

can be varied with ease. The tubes of broth are easy to keep at various temperatures, providing they are not too extreme, or in various illuminations, and the growth of the decomposers can be followed by using the simple device shown in Figure 3:8.

What combination of conditions gives the fastest growth for the decomposer used?

If another set of teams used a different decomposer, how might their most effective growth conditions resemble those found most suitable for the decomposer used by your teams?

Early in this section, decomposers were studied in terms of their effects on some gases in the ecosystem. Another important decomposer activity is the breakdown of complex molecules in the ecosystem to simpler ones. You can undoubtedly think of a number of useful decompositions that go on day after day. The breakdown of sewage is an example. So is the decomposition of plant material in the gardener's compost heap. Pollution workers use the term *degradation* for the breakdown or decomposition of complex substances. If the degradation is carried out by living things it is called *biodegradation*, and if a particular substance can be degraded by some living decomposer it is said to be *biodegradable*. Fuel oil and in particular certain pesticides such as DDT resist biodegradation. So do some of the chemicals in many detergents.

On the other hand, ordinary soap and a few detergents are readily biodegradable. Why is it commonly thought that biodegradable products are "good things" and that non-biodegradable materials are "bad things"?

In discussing the previous question someone may well have asked another one. What are the products formed when bacteria degrade a substance? The answer to this question could well change your views on whether or not biodegradability is such a good thing after all.

Laboratory Activity 3-6
Investigating biodegradability of detergents

There are several problems associated with a laboratory study of detergent biodegradability. Here are some of them.

How can one tell whether the detergents are breaking down or not?

How can the end products of degradation be identified?

Perhaps several different types of bacteria are needed to perform the degradation. Each type, in turn, could well attack only the breakdown products left by the one before. Or the degradation could be done by one type of decomposer only, but in distinct steps. First, it might attack and use up all of the original material. Then, almost as a second choice, it could attack its own first-stage by-products, using them as food until all is consumed. How can you be sure to have enough bacteria of the right kinds in your experiment?

Despite the difficulties, it is possible to perform some simple experiments to show how biodegradation works. For example, various soaps and detergents can be diluted with water according to manufacturer's directions. Into measured jars of each sample place a small but uniform quantity of mud from a river bottom or a swamp. (This provides a mixture of bacteria.) Check on the persistence of the detergent by taking a sample from each jar every few hours, or each day, and shaking it vigorously. Does the formation of suds change with time? How long does the foam persist in the test samples compared with the original material? It should be possible to devise ways of checking on the oxygen use and carbon dioxide production of the decomposers in the various samples by modifying some of the laboratory methods described earlier.

Try experimentally to connect the biodegradation of detergents with the ability of water plants (producers) to grow in the experimental jars. Consider the possibility that bacterial action not only breaks down the detergents but, by doing so, releases nutrients for the growth of plants.

In working with Laboratory Activity 3-6 a number of difficulties will probably have been encountered. These are the same kinds of difficulties that must be faced in most pollution studies.

It is often hard to be sure just what the polluting substance is. It is equally difficult to be sure one has identified the decomposer, or series of decomposers, attacking the pollutant. Moreover, it is not at all easy to discover what effect all of these substances have on producers in the ecosystem. Finally, it is very likely that what happens in the natural ecosystem is not necessarily the same thing that happens in the laboratory.

One example of these problems is the way in which phosphate-ion, freed from household detergents, has been blamed for greatly increasing the growth of producers, particularly algae, in natural waters. This situation is worth investigating. Is the blaming of phosphates justified? What other plant nutrients are released by decomposer action on pollutants? (See the questions at the end of Chapters 2 and 3.)

3.5 Coming Around Full Circle

We have worked at some length, first with producers by concentrating on their gas-exchange activities, and then with decomposers. The oxygen–carbon dioxide relationship was one aspect of the decomposer's action but we also looked briefly at the effects of decomposers in enriching the ecosystem for the growth of producers. Thus we have come around full circle.

What are the conditions that best favour the growth of aquatic producers?

Laboratory Activity 3-7
What conditions help producers to grow faster?

In this experiment, start with samples of the same kinds of water plants (Elodea or mixed algae from a fish tank or pond) in an attempt to determine what conditions most affect the plants in a given time. Many possible variables come to mind. Light, the amount of water, any fertilizers added, the detergents added, temperature, and the presence or absence of snails or fish, are a few.

Careful records should be kept, so that the conditions that work best and those that seem to have no effect can be re-examined and compared later.

A key question is how best to judge the growth of the producers. In some cases, merely looking at the culture jars will show which ones are most active. Try to modify the apparatus shown in Figure 3:8 if the producers being grown are algae. Another possibility is to filter the contents of each culture jar and weigh the plants trapped on the filter paper. There are, of course, other methods that you can try.

It should now be possible for you to make a fairly complete list of conditions and circumstances ideal for the growth of producers. How many of the conditions on your list are influenced by the abiotic environment? Which ones are dependent upon decomposers? Which conditions are influenced most by the producers themselves?

Questions

1. Nitrogen is one gas in the air that is not mentioned in Chapter 3. Why not? Investigate the importance of gaseous nitrogen to both producers and decomposers.

2. In Laboratory Activity 3-7, filtering and weighing were suggested as a possible means of judging the growth of a producer. Why was this method not suggested in Laboratory Activity 3-5?

3. It is implied in Section 3.4 that decomposers are useful in degrading many pollution substances. But most decomposers use up oxygen as they work. Thus, the natural decomposition of polluting chemicals demands a price in terms of a loss of oxygen from the streams.
   (a) What is biochemical oxygen demand (BOD)?
   (b) What is chemical oxygen demand (COD)?
   (c) How are they measured?
   (d) What is the meaning of high BOD in an aquatic ecosystem?
   (e) Under what conditions can producers themselves create a serious BOD?

4. The biodegradability of a detergent is related to the shape of the detergent molecule. You might try to find out which detergent molecules are most easily degraded. Use an organic chemistry text to look up alkyl benzene sulphonate (ABS), sodium alkane sulphonate (SAS), and linear alkylate sulphonate (LAS), and try to relate molecular shape to biodegradability.

5. Perhaps the producers in an ecosystem could have been called "composers" instead of producers. Use your knowledge of this chapter to form an opinion of the value of this suggestion.

CHAPTER FOUR

Consumers in the Ecosystem

4.1 A Complicating Factor

It is not difficult to imagine an ecosystem containing only two kinds of organisms — a producer and a decomposer. Each creature would reverse the over-all chemical activity of the other. Thus, each would live on the wastes of the other.

Such an imaginary ecosystem could go on cycling forever, provided that there was a suitable energy drive and an effective way for the spent energy to escape from the system. It might be of interest to try to invent such an ecosystem (see questions for Chapter 1).

Real ecosystems are not so simple. Just introduce a consumer into your imaginary two-organism model and you will see the immediate complications that arise. The presence of a consumer brings about changes in the ecosystem, and as you think about consumer activities such as breathing, excreting, moving, and eating, you will be able to list a large variety of ways in which consumers modify the ecosystem.

What effect have consumers on the numbers of producers? On the number of decomposers? Which types of organisms are in competition for gases? For food? For space?

4.2 Fish in an Aquatic Ecosystem

If you have done the kind of thinking suggested in Section 4.1, you have probably discovered the need to deal with real, rather than imaginary, organisms. Fish provide a good example of a specific consumer to work with.

Fish occupy a number of different positions, known as *niches*, in the aquatic ecosystem. Some feed directly on vegetation. Some are scavengers, eating dead animal matter. Still others are placed between these two on the food chain, and a number of fish eat almost anything they can find, and are thus consumers at several levels.

It is often helpful to express these ideas diagrammatically. Figure 4:1 shows some of the aspects of the life of a fish as a consumer. It is one thing to look at someone else's diagram in a book and quite another to make your own. For this reason Figure 4:1 contains a second diagram with several important parts missing — as a challenge to you to find out the various roles that fish play in the aquatic ecosystem and to express what you discover in a diagram of your own. (Draw this on a separate sheet of paper.) Try to refer to particular types of aquatic ecosystem; for example, you could select a farm pond, or a northern lake, or perhaps a stretch of river such as the Winnipeg, the Columbia, the Don, or the Ottawa. Try also to include a variety of fish species, such as minnows (say, shiners), pickerel (walleyes, doré), trout, bass, perch, carp, and others of interest.

By this time, it should be clear that if a living thing modifies the ecosystem, there is a good chance that the system will itself modify the living thing. If we dirty our own environment, we leave ourselves no choice but to learn to live in it. The same thing is true if someone else makes the mess.

If man cannot learn to live in the altered ecosystem, he must escape from it or die. If there is no place to escape to, then extinction of the species becomes the eventual, unavoidable conclusion.

Let us consider this in more concrete terms, using fish as an example. Suppose the pike and bass in a lake eat a variety of foods, but live mainly on young pan-fish such as perch, bluegills, and crappies. Anglers discover the lake and take only the

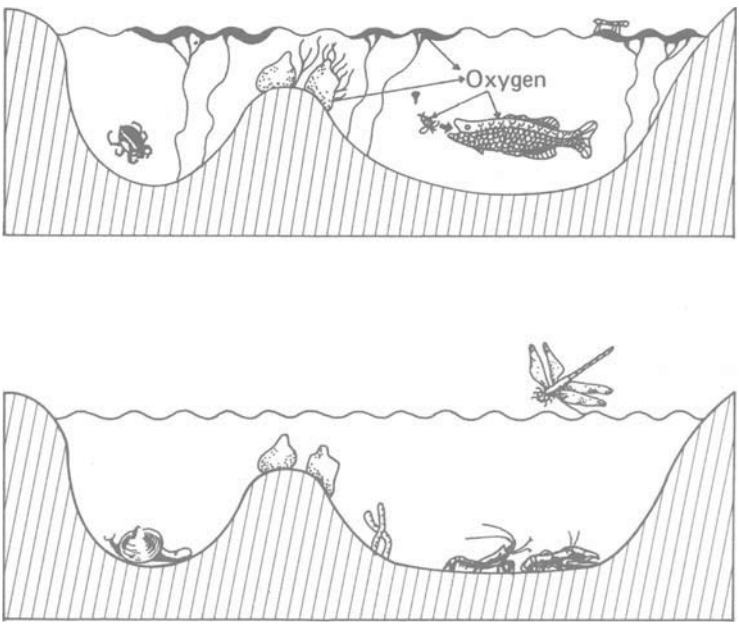


Figure 4:1 Some aspects of the life of a fish as a consumer. The lower diagram is incomplete. What details are missing? See page 64 for suggestions that will help you with the preparation of a diagram of your own.

game fish (pike and bass), leaving the coarser pan-fish. Try to predict how the numbers and sizes of the various types of fish will change over the years. What effect will these changes have on the producers and decomposers in the lake? An interested student should check his predictions with actual studies of lakes done in his area by government or private fish and wildlife biologists.

The case just stated shows one type of influence resulting from a consumer (in this case, man) hunting in a neighbouring ecosystem. It may suggest something about the "leakiness" of ecosystems — of movement of material from one kind of system to another. It may also lead you away from thinking about those game fish as modifiers of their own ecosystem. Suppose that there are no anglers on the lake. Suppose further that the pike and bass are plentiful and are successful breeders. Predict what will happen to the numbers of the various kinds of fish over the years. How do these changes affect the producers and decomposers in the lake? What is the "built-in" means of control over the kinds and numbers of consumers in a natural ecosystem?

The examples so far have required you to think about the effects of fish as consumers upon their ecosystem. It might be wise to take one case in reverse and inquire how a change elsewhere in the ecosystem reacts upon the fish. Suppose that we have a lake containing four species of fish. Species A will begin to die out when the oxygen content of the water drops below 8 parts per million (ppm). Species B requires a minimum oxygen level of 6.4 ppm and species C needs 4.9 ppm. Species D is very efficient in its use of dissolved oxygen and can live and reproduce in water containing only 3 ppm of oxygen. Assume the lake originally contained a minimum of 14 ppm of dissolved oxygen, and further imagine that all four kinds of fish are living in the lake and that no one species depends upon any of the other three for food. Now work out what things could happen over a few years to the kinds and numbers of the four species if the oxygen content of the water dropped by 1 ppm each year.

This problem can be — and is — varied infinitely in nature. For example, suppose that species D depended upon species A for its chief supply of food, and the oxygen level became lower and lower. Or, imagine that species C can live but cannot reproduce at its lower limit of oxygen need. With each variation in the assumptions suggested above, predict what things could happen to the kinds and numbers of fish in the lake.

4.3 Busy Beavers

Before thinking about man as a modifier of his environment, it will be useful to discuss another example of the ways in which a consumer can alter its ecosystem. The beaver has been a symbol of Canada for many years and its habits have often been admired as virtues. Let us see what the hard-working beaver can do to an area.

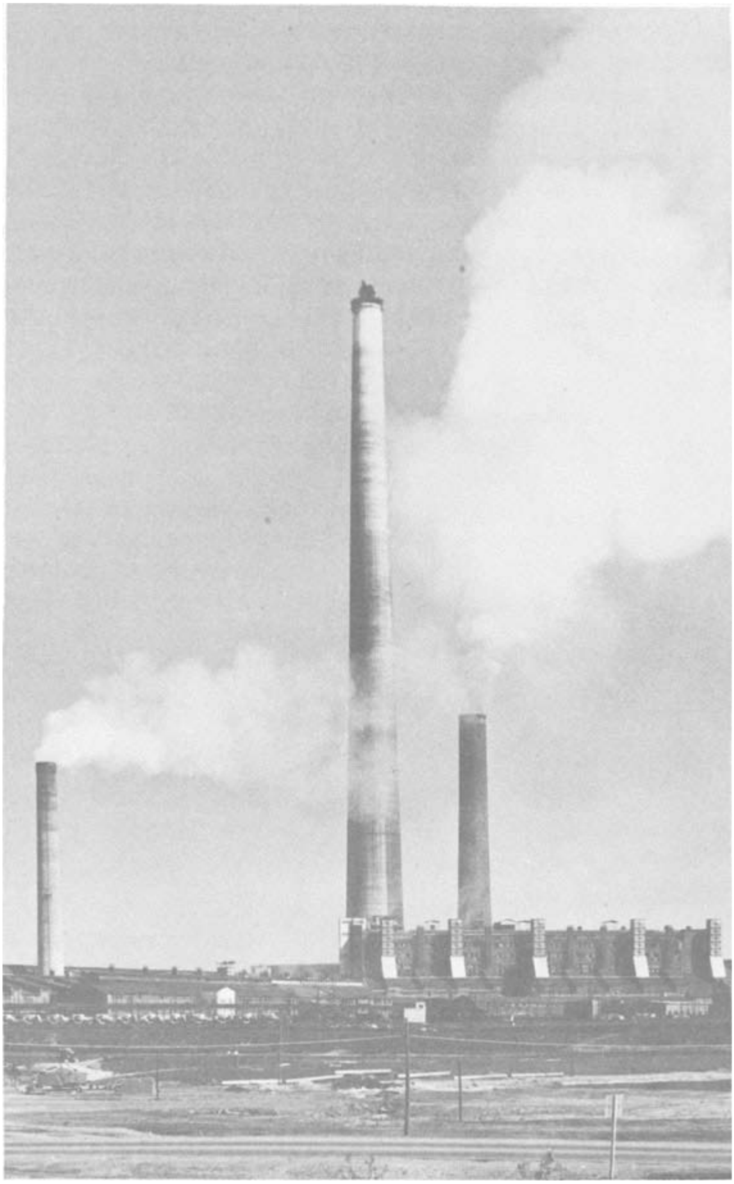
Imagine a wooded region with a creek flowing through it. The trees are mixed birches, aspens, and various evergreens. A pair of beaver arrive and begin to drop the birch and aspen trees near the creek. They feed on the bark and twigs. The branches are used to build a dam across the creek. The dam leaks a great deal at first, but as more and more branches are wedged into position, and as mud and stones are added, the dam begins to hold back water. The water level rises and a pond begins to form above the dam. The beaver fell more trees, still selecting aspen and birch, which they either store underwater for food, or use to build a lodge in the pond. The dam needs, and gets, daily repairs.

As the years go by the number of beaver increases, the dam is enlarged, and so is the upstream pond. Supplementary dams may be built to prevent water from spilling out of the pond. Narrow channels are dug into the shore to help float more distant trees to the main pond. Eventually, a number of distinct changes begin to occur in the area.

The selective cutting of aspen and birch gradually reduces the food supply available to the beaver. In some cases the beaver will literally have "eaten themselves out of house and home" since they use up trees much faster than the trees grow. When this happens the beaver either move to another location if they can find one, or starve, or fall prey to predators.

There is also an effect upon the forest of the region. What was once a mixed forest is now much more uniformly an evergreen forest. Furthermore, the pond has flooded an area of forest and killed those trees and shrubs that cannot tolerate being under water. The pond itself is a very different habitat from the original creek. A new set of plants, worms, snails, insects, and fish now thrive there. In very old beaver ponds, the vegetation, especially grasses, may grow so vigorously that the pond is finally filled in and becomes a damp, lush, swampy meadow. This is the so-called beaver meadow.

The point being made here is that the beaver is an example of a consumer that causes major changes in its environment. The results of those changes eventually make the environment unsuited to beaver. The changes cannot be reversed. The region never goes back to the original creek flowing through mixed forest.



The use of tall stacks carries waste gases and dusts high into the air. Someone once jokingly called this "sharing the wealth". Scenes like this are common in every industrialized region. What are the alternatives?

4.4 Man the Modifier

Of all of the consumers in the world, man is possibly the ablest, and certainly the most persistent, modifier of his ecosystem. In general, we think this to be a great advantage. If we do not like something, we simply change it. If an apparently idle swamp can be made useful to man by draining it, we often do so. If the energy in a flowing river can be converted to a useful form, we dam the river and control its flow. If our clothes, or containers, or appliances get dirty, we wash them and throw out the dirty water. You could probably make a list of hundreds of ways in which humans, now and in the past, have been modifying the ecosystem. As you build your list, think of prairies and forests; include hunters and herdsmen; consider paper and pastries and plastics; give attention to furnaces, freezers, and rodent poisons.

Having compiled an extensive list of ways in which man modifies his environment, you may have felt, among other things, that some of the changes are pretty serious and others are quite unimportant. It is curious, but quite natural, that many humans do not recognize the seriousness of a situation until people start to die in large numbers. As an exercise pointing up this indifference, compare the newspaper coverage given to a recent air crash with the coverage given to the accident fatalities on a long holiday weekend, which may involve as many or even more persons. You might care to make a study of man-made ecosystem changes that have had, or may yet have, serious consequences. The Donora, Pennsylvania, disaster in the United States was mentioned in the questions following Chapter 1. In this situation and others like it — for instance, the famous Los Angeles smogs — the air component of the abiotic environment is altered.

Another example for which a massive amount of information has been gathered is that of Lake Erie. There, man's activities have drastically speeded up the alteration of an aquatic ecosystem. Other examples you might consider include the oil spills in the Pacific (off Santa Barbara) and in the Atlantic (the tanker *Arrow* in Chedabucto Bay, the tanker *Torrey Canyon* in the English Channel); the problems in the Dunnville, Ontario, area; the case of the poisoned fish in Placentia Bay, Newfoundland; and the series of ecological disturbances that appear to be following construction of the Aswan High Dam in Egypt.

The sinking of the tanker *Torrey Canyon* dramatized the importance of oil spills to the environment. Why is oil so damaging to the ecosystem? Who creates the demand for huge quantities of oil to be transported? What are the alternatives to shipping oil by sea?

4.5 The Value of Diversity

There is a value in diversity that may be seen in the natural environment as well as in the realm of human affairs. Think of a clothing store that sells only formal dress for evening wear. Then think of a competing store that sells formal clothing as well as garments for work, business, sports, and casual wear. Which store is likely to operate more steadily all year long? Which store will more likely survive drastic changes in social customs, population shifts, and depressions?

A similar relationship exists in ecosystems. The one having a large variety of different species is more stable. Changes in climate from year to year may favour one species somewhat more than another, but all continue to be present and the ecosystem remains stable. A system such as this has a kind of natural internal shock absorber, owing to the diversity of species, that allows it to remain essentially unchanged over quite long periods of time.

On the other hand, an ecosystem that has relatively few species is much less stable. All of its eggs are in one basket, so to speak. A failure of one member of the ecosystem may seriously interfere with the whole system and bring it to collapse. The effect of much human activity is to reduce the diversity of natural ecosystems from many species to few species. Indeed, in some cases, one could say that human manipulation leads to the growing of only one kind of plant or animal. This activity is called *monoculture*. The case of wine fermentation, used to introduce ecosystems in Chapter 1, is an example of monoculture.

Let us mention two examples of the tendency for human activity to produce unstable monocultures. After reading these, try to add your own examples to the list. The first example is the conversion of a mixed forest to apple orchards. An area of forest containing, perhaps, fifteen species of trees (plus hundreds of species of other plants, insects, birds and mammals) is cleared and planted with apple trees. Not only is the diversity of trees reduced, but many other species will have lost their homes. The environment is now less stable. The apple trees are concentrated in one region. There are no other kinds of plants separating them. It is nearly a monoculture and very susceptible to many hazards, including the spread of diseases and insect pests.

The second example is a consequence of the first. The substance DDT has been widely used to poison insect pests. DDT is a general poison and kills *all* of the insects it reaches, including those that normally eat the pests. DDT has other dangerous properties, but our concern here is with its tendency to decrease diversity. A few insects resist DDT and survive the treatment. These reproduce, and the pests reproduce more rapidly than do the less numerous beneficial species that eat them. This means that the insect pest situation eventually gets worse rather than better. More spray is used and once again the diversity is reduced. The combination of the orchard monoculture and the DDT sprays results in the development of a very fragile, easily disrupted, and unstable ecosystem.

4.6 Close to Home

It is always interesting to study famous cases of severe environmental change caused by humans far away. It is also easy for us to feel indignant, or angry, or even superior to those poor, distant people who have got themselves into such a sorry condition.

But what about the changes in your own environment? It could well be just as interesting, possibly just as instructive, and probably much more uncomfortable, to investigate the ways in which your own environment has changed over the years. One way to do this is to ask older people what the area was like in the past. Some of the people you interview may have old photographs that will help you to construct an historical picture of the changes that have occurred.

If you live in a city or town, a study of the invasion of the rural ecosystem by the city may form an important part of your study. If you have the opportunity to speak to men and women who have lived and worked outdoors, you can learn how hunting and trapping has changed over the years in an area, or how the building of dams has changed a river and its lakes. People who have had a cottage for many years could be a good source of information about the changes in and beside a body of water.

Another method of making your work more revealing is to undertake a local pollution study. It could begin right at your school. When science students clean up their glassware, where do the chemicals, the soap, and the rinse water go?

You could arrange with your teacher for a field trip to examine, measure, or simply experience a pollution site in your own locality. What happens to the empty sardine can you put in the kitchen garbage bag? If you have not already done so, spend some time at your municipal dump, savouring the air and relating what you sense there to the nature of your ecosystem. What becomes of the rainwater that falls on the dump? Your field trips could include a visit to a small industry, or you might collect and analyse water samples along a stream.

Your most important discovery may well be that it is easy to blame other people for changing the ecosystem without realizing that each of us, personally, is doing the same kind of thing. In fact, you may conclude that laying the blame for pollution is really not a helpful exercise at all. Consumers, especially human beings, all modify their environments, and it is up to us to understand the processes involved before accusations are made.

4.7 Improving the Environment

If man can make changes for the worse in ecosystems, it should not be too much to hope that he can change things for the better. Possibly we can find ways of using our knowledge of the behaviour of ecosystems to bring about improvement rather than damage. So far, the record of environmental changes started by human tampering is heavily weighted on the side of harm to the ecosystem, but there are a few cases of improvement on record.

Not very long ago, one of the world's most polluted areas was the city of London, England. The River Thames was virtually barren of life. The air in the city was smoky and often filled with black flecks of soot. The naturally occurring fogs combined with the smoke from hundreds of thousands of chimneys to produce a thick, poisonous atmosphere that seriously interfered with breathing and was responsible for many deaths. That particular situation has now been radically changed for the better. Fish are now being caught in the Thames. The London air is much better for breathing. Find out how the Londoners did it. Find out, if you can, how much it cost.

The St. Lawrence River from Montreal downstream has recently come to public attention as a seriously polluted stream that has yet to receive any of the kind of treatment that may result in an eventual improvement. A report published in 1972 described the chemical and bacterial content of the water from Montreal to below Quebec City. Some of the bacterial counts are shown in a graph in Figure 4:2, along with the bacterial level considered safe for swimming. The bacterial pollution of the river is due primarily to the fact that most cities along the river empty their raw sewage directly into the stream. Whatever goes into the toilets in those communities goes more or less directly into the river. Scientists who study the river water know that this is so because the bacteria they count are normally found only in the human intestine. The point is that, unlike the River Thames in England, the St. Lawrence in Canada is seriously polluted. Small, isolated control measures will not help much. A large-scale, co-ordinated effort is required to make the St. Lawrence a reasonably healthy river again.

Pollution control measures have been attempted in other places. Two examples are Lake Washington in the United States and the Red River in Manitoba. You should investigate the effectiveness of either — or both — of these. There may be an active environmental improvement project going on in your own locality. In many places, groups of interested people are trying to improve a local lake, or a creek, or a duck marsh. How successful are these attempts at restoring ecosystems to health? What is the cost? For that matter, does a consideration of cost have any real meaning? Is a clean lake worth more, in actual dollars, than a filthy one? How could you approach the problem of making a reasoned decision?

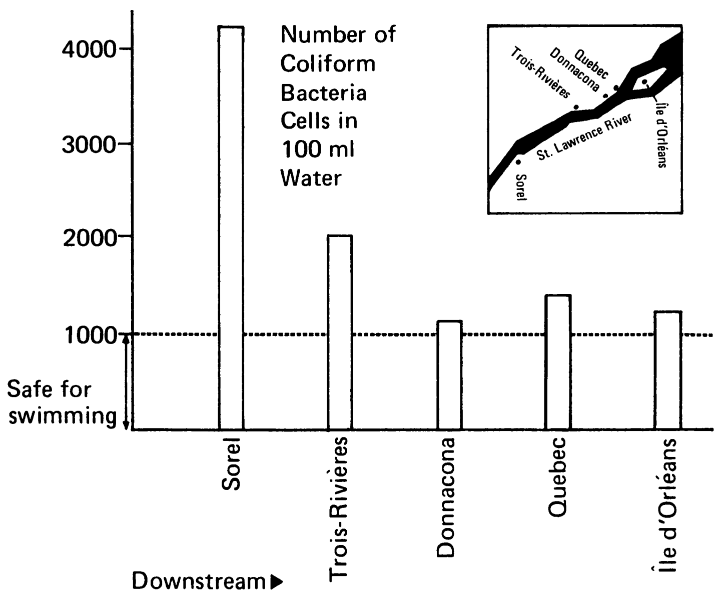


Figure 4:2 Graph of some of the counts of intestinal bacteria found in St. Lawrence River water. (Data communicated by Noel and Simard, June 1972)

An understanding of the processes that go on in any ecosystem will help people to make desirable changes wisely. The trick is to change the ecosystem to permit the kind of life one wants, while at the same time keeping the ecosystem working. You have already gained a great deal of the knowledge that will be helpful to you as a citizen in working out ways of restoring — and maintaining — a high-quality environment. One theme throughout this book has been the cyclical movement of substances through our environment. In stable, enduring ecosystems, matter given off as useless by one organism is used as food or for breathing by another.

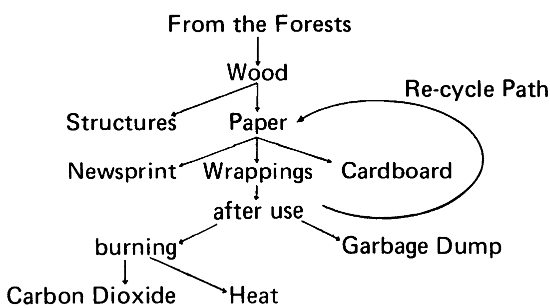
How does the idea of cyclical use of chemicals apply to the human situation? Most industries that use an expensive substance in the manufacture of a product are careful to recover the costly material so that it can be used over and over again. One example is the heavy water used to control, and sometimes cool, nuclear reactors. When industries and municipalities come to value their normal water supplies highly enough, they may actively seek ways of processing their dirty water for re-use rather than throwing it away. Try to find a number of current examples of cyclical re-use of basic substances such as water. The Milwaukee sewage treatment system is an example, the processing of smoke and of slag in mills and refineries is another, and the conservation of heat in steel mills is a third possibility. You can also investigate the extent to which paper is re-used by paper companies in place of raw pulp.

Also examine the other side of the coin. What are examples of the one-way use of substances that could be converted into cyclical use? Figure 4:3 shows a number of possibilities to explore. You will be able to think of many others.

It is possible, as you will have observed by now, for people to restore and improve the human environment. We have enough knowledge to make a good start, but whether or not we have the will — and are prepared to spend the money — to solve the many practical problems is another matter. Consider just one case. Automobiles are a major cause of air pollution. City streets are often literally plugged with masses of automobiles. A large proportion of automobiles carry only one person to and from work.

Why, then, don't people get together, load up their automobiles with passengers, and reduce both traffic and air pollution at

a. The non-cyclical use of iron



b. The partial recycling of paper

Figure 4:3 Two schematic diagrams illustrating the cyclical and non-cyclical use of material. A. The non-cyclical use of iron. B. The use of paper. How would diagram A look if people decided to re-use these materials? What justification is there for saying that our use of iron involves little more than digging it up in one place and burying it in another? Make a similar diagram for glass.

the same time? Or why don't they get together and hire small commuter buses? You know that there are a great many different reasons for people not coming to grips with the automobile pollution problem. If you look closely, you may find that all of those stated reasons can be reduced to one basic cause, or at least to a very few causes. Do not fall into the trap of laying *all* of the blame on the automobile manufacturers.

Can you think of other cases where we have the capability of solving pollution problems but still fail to do so?

4.8 Some Impossibilities

It is clear that there are a great many possibilities for improving, restoring, and maintaining healthy ecosystems. If people will understand their place as consumers and modifiers within the system, and if they will then apply their ingenuity and skills to environmental problems, a great deal can be done. Even so, a great many things are simply not possible. These things should still be considered, however, for it is a dangerous practice in science to regard anything as impossible. History has shown many times that the impossibilities of today become the commonplace events of the future.

At this point, it would be helpful to review Section 1.5. The main purpose of the section is to show that energy does not cycle through the ecosystem as matter does. Instead, energy has a one-way flow. It is constantly being lost from the ecosystem as waste heat.

This leads us to consider our first impossibility: Many forms of pollution are related to our use of energy; for example, electric generating stations and petroleum burners, including furnaces and cars. In a similar way, many pollution control systems themselves need energy. Thus, getting rid of one form of pollution may well generate another form. Can you see any way of avoiding eventual thermal pollution of the world? How can we possibly avoid generating heat, and thus raising the temperature, if our consumption of energy (and dispersal of waste heat) continues to go on at its present pace?

Another aspect of the same difficulty is the connection between energy use and the standard of living. The higher the standard of living, the more energy we use, and the more heat is produced. Someone has said that almost all of the material gains of this century are things that we plug into wall sockets. It has also been suggested that the Industrial Revolution was wrongly named; it should have been called the Energy Revolution. These notions may help you to grasp something of the impossibility of avoiding pollution problems that are due to large-scale energy conversion.

Which one of you will be the first to give up your favourite energy converter — be it a television set, a motor bike, a car, or a snowmobile?

Another impossibility is worth mentioning even though it concerns an unknown factor. It revolves around the question of whether it is possible to repair an ecosystem no matter how badly it is damaged. If there is a point of no return for ecosystems, then we could face the impossibility of restoring an ecosystem that has passed that point. The difficulty is that no one really yet knows what the points of no return for particular ecosystems really are.

Let us look at some ecosystems which may have been pushed beyond the point of no return. Some examples are related to the changes that occur when the soil cover and topsoil are removed. There is the case of the man-made deserts or dust bowls. First, the natural grasses were removed to permit farming the fertile soil. Then, cultivation of the soil left it exposed to the wind most of the time, and in periods of drought the topsoil blew away, leaving only the useless subsoil and larger sandy particles to form barren, deserted dunes. Only a few of the hardiest plants can grow under these conditions. It would seem that these grassland or prairie ecosystems were damaged beyond repair, for where can the lost six or eight inches of topsoil be found? And, if found, how can it be held in place when the wind blows across the flat, treeless plain? Some scientists think that portions of the North African deserts were formed in just this way. Certainly the dustbowl areas of Saskatchewan and the American Midwest were formed by a combination of overcultivation, drought, and wind erosion.

Similar cases are to be found in the practice of strip mining in many Canadian provinces. In this case the plant life, topsoil, subsoil layers, and lower layers are treated as waste materials. They are dug up, hauled away, and dumped in order to expose a desirable, mineral-bearing ore. In recent times, the ecosystems disrupted in this way have never been restored.

Still other examples of possible irreparable damage to ecosystems may be found in cases where either a new foreign species of animal or plant is introduced into an area, or where an existing species is destroyed. An example of the former is the introduction of the sea lamprey into the Great Lakes. An example of the latter is the effect that the heavy reduction in the number of prairie gophers has had upon the animals that normally feed on them.

There are two other unpleasant avenues to be explored: One stems from the fact that polluting substances, often complex, man-made molecules, are extremely hard to get rid of. There is simply no place to put them. Many so-called pollution control operations consist of the bundling up of the polluting chemicals and the moving of them from one place to another. Consider the disposal of radioactive wastes as one example, and the disposal of DDT stocks as another.

Finally, each day, there are an increasing number of people alive on earth to modify the global ecosystem. An ecosystem that will support one hundred humans without noticeable strain may change slightly when required to supply one thousand. The same ecosystem would almost surely be seriously damaged with ten thousand humans in it, and with a hundred thousand people competing for a share of the same ecosystem's matter and energy, the situation is likely to become impossible.

The city of Toronto provides a specific example. The city and its immediate area contain more than 2,000,000 people in a highly industrialized human complex. It functions by drawing raw materials — some of them not replaceable — from all over Canada and even from other nations. It converts these materials into consumer goods and dumps all of the waste products in one small area. Not only must the ecosystem take this, it must handle the sewage of more than 2,000,000 human beings crowded into a relatively small space.

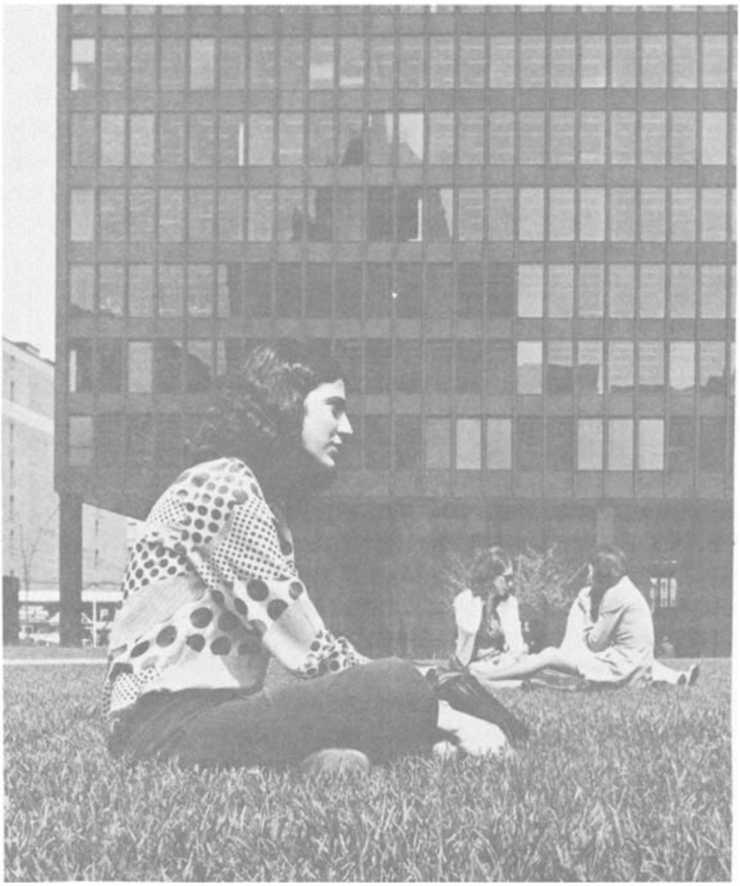
It will be recalled from earlier sections (Section 4.5 in particular) that there are natural mechanisms that tend to regulate the numbers of consumers in an ecosystem without destroying it.

Mankind has been unwilling to submit to regulation of his numbers, and the ecosystem will ultimately be strained beyond its capacity.

Questions

1. Crayfish in a creek need oxygen to live.
   (a) Where do they get it?
   (b) As the crayfish continue to use up oxygen one would expect the supply to run out. Why doesn't it?
2. Section 4.3 describes some of the effects that beaver may have on their environment. Make a list of the similarities to be found between beaver and men as modifiers of their environments.
3. In July 1970, a technical adviser to the President of the United States of America issued a public warning that the heavy use of air conditioners could possibly cause a serious shortage of electrical energy.
   (a) Name the ways in which the operation of home air conditioners modifies the environment.
   (b) If an air conditioner removes heat from a house, where does the heat go?
   (c) Trace the connections between use of air conditioners and pollution problems.
4. Investigate the possibility of using the oceans as a kind of global garbage dump.
5. It has been said that the best solution to the garbage problem is to burn it all. Why is this no solution at all?
6. What is meant by the expression "balance of nature"? Write a carefully considered answer giving specific examples.
7. The size of any population is controlled by the relation between the number of creatures born and the number that die. Predict the future of a population that has the following properties:

(a) natality is less than mortality;
(b) natality equals mortality;
(c) natality is greater than mortality.
(Be sure to indicate any assumptions you make as you work out your predictions.)



CHAPTER FIVE

Cities and the Web of Life

5.1 Radiating Ripples

A stone falling into a pond causes ripples that spread out in all directions over the water surface. The same sort of thing happens following a change, however small, in an ecosystem. This is also true for a topic of study. Investigations in environmental pollution can lead into the fields of biology, chemistry, physics, meteorology, and other sciences. They can also lead into areas of study that are more socially oriented. These include the social studies, business, social geography, and history.

It is quite possible that some of you may have thought of linking environmental studies with the arts. How does crowding affect poetry? Perhaps it requires artists, writers, and composers to arouse people to the pressing nature of pollution problems.

The aim of this chapter is to relate the insights you have gained, and the facts that you have recognized, to your own personal way of living. You will be asked to relate these things not only to yourself as a person, but to your community, your county or district, your province, and your country. The idea is that you should find out some of the ways in which individual persons, society as a whole, and ecosystems, all interact.

Consider the following environmental problems in their social setting. In thinking about these problems, and about society's reaction to them, you may feel the need to become involved in subjects other than science. The problems are presented in a way that should make it easy for you to consult and work with the teachers of these subjects. In some cases, the nature of the problem may prevent a cross-disciplinary approach, but try to use *all* that you know in working out your thoughts on each one.

Finally, it is hoped that some students will move out far enough from the details of this book to see the need for men to live in harmony with their ecosystem. It is possible that harmonious relations within the ecosystem will require men to accept certain limitations imposed by the ecosystem. This means that people may have to practise a number of restraints. They may have to change their views about many things that are "nasty" and "bad". In fact, you may have to do all of these things and more, if you and your kind are to succeed as members of a functional ecosystem. Primitive man managed reasonably well on a low-energy budget. Modern man may have to learn to manage again in this way.

5.2 Putting On the Pressure

Man the consumer has always exerted pressure on his environment. In each of the two following cases, investigate the historical aspects of man's use of the resource involved. Try to find out how it started, how it developed a strain on the environment, and what the present situation is.

CASE 1: Rubber

How was rubber first used, and how was it obtained? How has rubber consumption changed since 1900? What are the connections between synthetic and natural rubber? As rubber tires wear out, where does the rubber go? Calculate the yearly loss (disappearance) of rubber in your community.

CASE 2: Paper

(a) The same questions as in Case 1 apply. You should also investigate the connections between the increasing demand for paper, the spruce budworm, and ocean DDT levels.
(b) Make a study of some daily newspapers for at least a one-week period. Read the papers completely and critically. What would happen to our society if the supply of newsprint were exactly half what it is now?

There is a common belief in some parts of the world that any system must keep growing in order to survive. This belief is expressed in the saying "If you stand still, you're dead." Consequently, there is a social conviction that economic growth is always a "good thing". Economic growth, to a business, means increased production, increased sales, increased wages, more profits. To a municipality, economic growth implies more industries, more families, more revenue, more services, and so on. You have probably gained enough insight into ecosystem-function to imagine what could happen to an ecosystem if it practised "economic growth" over a sustained period of time (see Case 5).

One aspect of economic growth that concerns each of us directly is the part that we, as individuals, play in creating consumer demands. Figure 5:1 illustrates the way in which individuals create pressure, and in turn are pressured by the economic growth habit.

As you examine the diagram, consider the distinction between a "want" and a "need". Also consider whether or not advertising deserves as much weight as it is given in the scheme shown. Can you make a better schematic arrangement?

CASE 3: Hit Songs

Try to analyse what goes into the making of a hit song. How does a song get started? What makes it first appear on the charts? How does it rise (and fall) on the charts? Why do different listings of the top tunes vary in the same week? How could

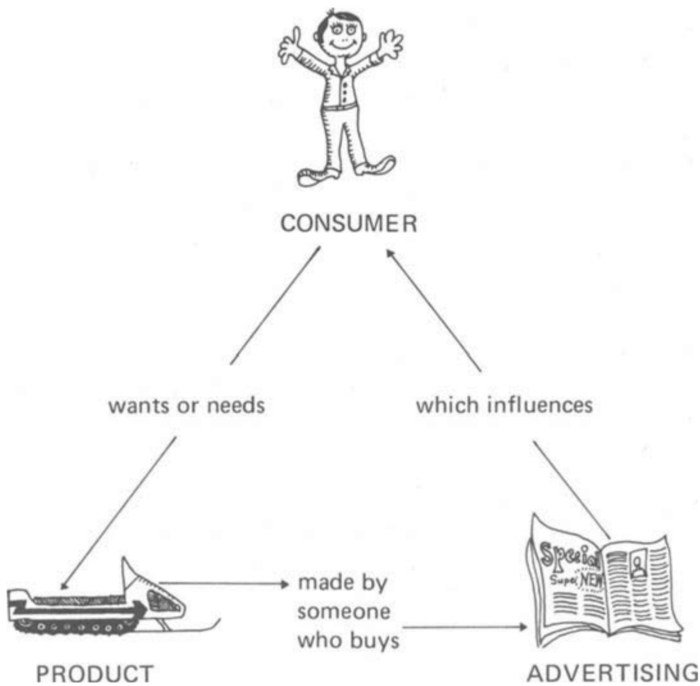


Figure 5:1 The consumer-producer relationship in terms of human society.

your class influence the charts in your area? Does your analysis support or deny the ideas expressed in Figure 5:1?

CASE 4: The New and Improved Model

Select some commercial product that interests you. It could be cosmetics, laundry detergents, automobiles, snowmobiles, outboard motors, sewing-machines, cereals, or typewriters. How has the product changed over the years in construction, in performance, and in cost? Which of the changes have been genuine improvements in terms of performance, value, and serviceability? Which of the changes have been novelties introduced simply for the sake of something new? How are the changes advertised, and to what extent does this create a demand for the "new and improved" product?

CASE 5: An Expanding Ecosystem

Imagine an ecosystem such as a pond, with its grassy banks, its weedy bottom, and the air above it, sealed into a huge transparent plastic bubble. Now apply the ideas of an expanding economy to the ecosystem. The producers are to increase in number and in productivity. The consumers and decomposers are to consume faster and decompose more. *You can assume that the plastic will admit as much energy as is needed, but will not allow any substance to enter or leave the closed system.* Describe the changes that you think would occur. How would the description change if you change the assumptions? How applicable are these ideas to our entire planet?

You may have decided to take one or two cases in this chapter and concentrate on them, or you may have looked at each in turn rather briefly. Either way, it should have become apparent to you that each one of us puts pressure on our society and is in turn pressured by society. These pressures have more or less direct implications for the environment. A striking example provides the background for Cases 6 and 7. You may also think by now that the exertion of pressure is an utterly "bad" thing.

Through deeper investigation of the problems, you could also conclude that the existence of these pressures is a normal and natural thing. Somehow we must find an acceptable balance between the pressures we generate for more goods and services, and the opposing demands now being made for a high-quality environment.

CASE 6: The Great Outdoors

More and more people are getting to know the satisfactions and recreation that come from living outdoors. Increasing numbers of people are finding genuine refreshment in the silence of a distant lake, in the brilliance of the stars away from cities, or in the cry of the loon. The importance of the restorative powers that come to a large proportion of the population from living in more or less primitive surroundings cannot be overemphasized.

People are realizing that they need the wilderness. This need, multiplied by the number of those who feel it, exerts a severe pressure on the wilderness. Investigate the use of a provincial or national park in your area. How has the number of recreational visits changed over the years? How much real wilderness is there? What pressures exist for the commercial use of parks resources? How does technology (the use of motor boats, chain saws, snowmobiles) affect the park areas? How close is your park to being polluted?

CASE 7: Tourism

A tourist operator decides to "open up" a previously unused lake. He buys land, puts in a road, and constructs a large resort centre with dining and recreational facilities, cabins for guests, a launching ramp, and marina service. The development costs several hundreds of thousands of dollars and gives employment to a variety of construction workers, maintenance men, cooks, waitresses, and guides. Each year the resort provides pleasure and recreation for hundreds of guests who have read about it in the newspapers or travel brochures and have been attracted to it. The operation of the resort also results in changes in the environment: for example, a large septic tank with drainage beds has been required; perhaps, also, the operator undertakes to control mosquitoes and other pests.

State the arguments supporting this development as a wise use of a natural resource area. State the arguments supporting the view that the development is an abuse of the area. Which set of arguments do you find more convincing?

5.3 Dependence and Independence

A young child provides a good example of almost complete dependence. The child relies upon others to provide the necessities of life: food, clothing, shelter, and protection from all kinds of hazards. It also depends upon others for instruction and affection. In healthy families, as a child ages, it grows away from the

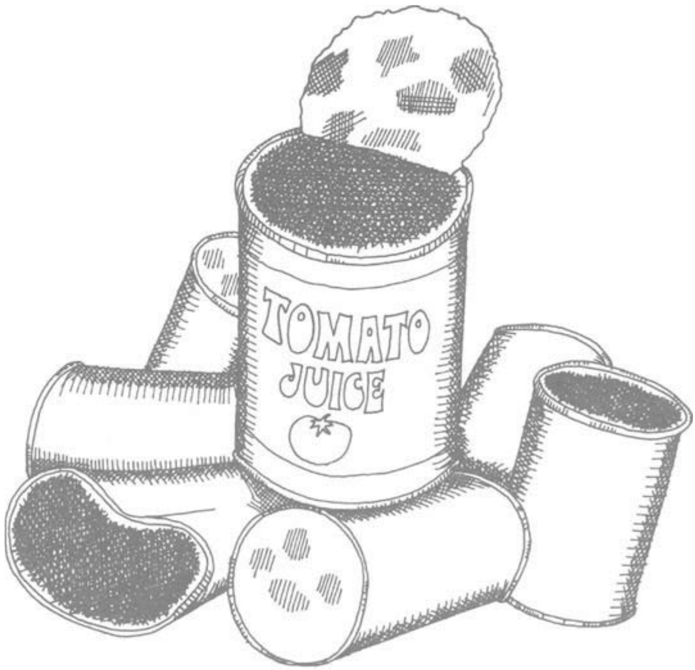


Figure 5:2

state of total dependence. It is usually with a strange mixture of delight and regret that parents view the increasing independence of their children. You might now begin to wonder what constitutes genuine *in*dependence. What things can truly independent men and women do for themselves? For what things must the so-called truly independent man or woman rely on others? And, finally, in what sort of environment, in what sort of social structure, do you picture the completely independent person living?

If you have thought about these questions and have discussed them with your classmates you have probably learned something about the ways in which individuals are bound together by a network of dependencies. The ideas that you have worked with are particularly relevant to the current trend of movement from rural areas into cities. The population of country-dwellers is steadily shrinking. An increasing number of people are living in cities. It has been estimated that eight out of every ten Canadians will live in cities by 1980.

The table below and Figure 5:3 give information about the distribution of people in the United States of America. What percentage of Americans would you predict will live in cities and towns in 1980? What conditions could reverse the trend for people to move from the country to the city?

Table showing the percentages of the human population found in urban and rural areas in various years

	Percentage of the population	
Year	*Urban*	*Rural*
1800	6	94
1850	15	85
1900	40	60
1960	70	30

Case 8 requires you to think about the reasons for the growth of the cities and the effects that city living has upon the independence of individuals.

CASE 8: Gracious City Living

(a) Try to think critically about the advantages of living in a city. It may help to make a contrast with life in the country. Whether your school is a city school or a country school, you might arrange a class visit with a corresponding school in the other situation. As a result of your work, build the following lists:
  (i) The advantages of city life.
  (ii) The disadvantages of city life.
  (iii) The things for which city dwellers are almost completely dependent on others.

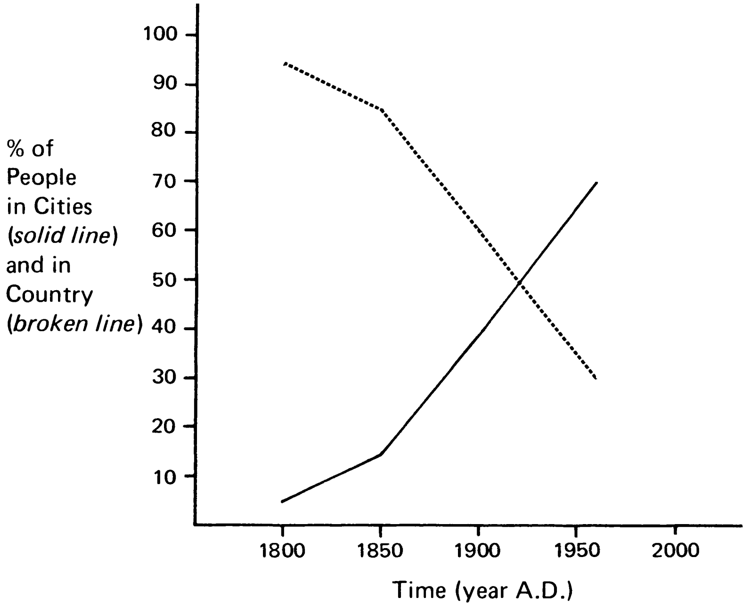


Figure 5:3 Graph showing the percentages of the human population of the United States that lived in the country and in towns and cities. Try to estimate from the graph what the percentages might have been in 1750 and in 1700. Do your estimates make sense? In what year were there equal numbers of city dwellers and country dwellers?

(iv) The things for which country dwellers can be almost independent of others.

(b) As an alternative to the problem above, you might prefer to trace the path of a food item, say a hamburger bun or an apple, in the city. Start with the arrival of the raw materials in the city, trace them through their processing; follow the bun through its distribution to the wholesaler, to the retailer, to the consumer, its transit home, its consumption, and the disposal of the wastes created (include both sewage and garbage). Indicate the degrees of interdependence of people at each stage of its path.

The growth of the cities, and the increased number of interlocking dependencies that develop, affects not only individuals but also industries, and the location of industries creates some serious problems involving the wise use of land. It is important to build an industry in a place with easy access to the needs of that particular industry. You can list many of these specific needs as they relate to transportation, energy, water, the labour force, and markets. Case 9 invites you to consider some land-use problems.

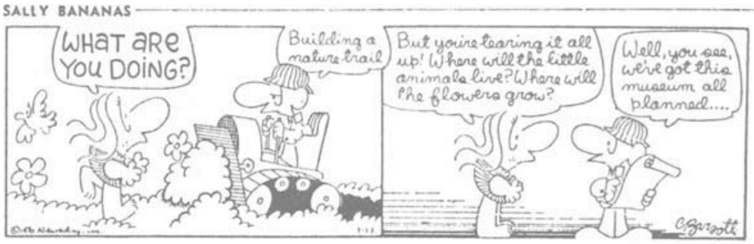
CASE 9: Wise Use of Land

(a) Suppose you are an elected member of a township council. An industry called Peerless Building Supplies applies to build an establishment on a twenty-acre piece of land in your township. A rail line passes near the lot, so that lumber, bricks, cement, roofing shingles, and other supplies can be brought in easily. There are large suburban subdivisions being built near by so that there is a need in the township for the type of industry that can design and build houses and supply materials.

On the other hand, there is at present a market garden operating on the twenty-acre lot. The soil is well suited to this operation and the owners, while willing to sell out for a large sum, are providing a needed service to the community. One member of the township council is in favour of granting permission for the sale of the land and the establishment of Peerless Building Supplies. Another member is opposed. He thinks the industry should be encouraged to locate on a more distant piece of rocky wasteland. Where would you stand on the issue? How would you vote, and why?

(b) As an alternative to the problem just stated, investigate the nature of the actual land use in your own locality. What industries have come in? What factors determined their location? What effects have the industries had on the community? What rules does the community have to govern how land is used? What sort of planning is your community doing to ensure the best possible land use in the future?

As you have read this section, and perhaps paused to think about some of the questions, you may have felt that city living



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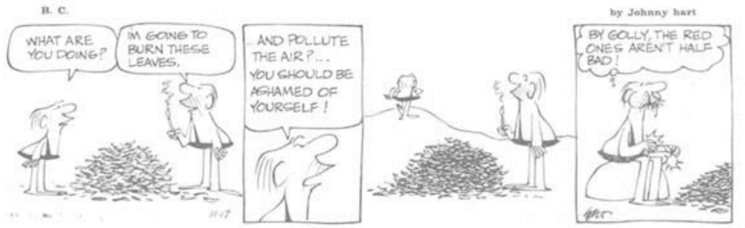

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Figure 5:4 Ecology in the comics.

tends to bring individual people into conflict with groups of other people. Sometimes it is annoying to be dependent upon others for so many things. Sometimes the rights and needs of one group of people interfere with the rights and needs of other groups. You could well have included such conflicts in your work in previous case studies. Case 10 provides situations in which such a conflict is the central issue.

CASE 10: A Collision of Interests

(a) The city of Kingston, Ontario, like every other city, has a continuing garbage disposal problem. In this case there is a large tract of marshy "wasteland" that is being filled with garbage and soil. A municipal golf course is planned for the area when it is filled. There are also plans to build an eighty-foot-high mound of garbage, covered with soil fill, to form a ski hill. Here are some excerpts from the July 28, 1970, edition of the *Kingston Whig-Standard*:

The city dump ski hill is turning into a mountain of controversy, much to the chagrin of Montreal street residents who are opposed to the location of the 80-foot mound of garbage and earth-fill.

Ald. James Cook and Ald. Herbert Hunter assured City Council Monday night that dumping operations on the hill would be halted, at least until the next meeting of council in one month's time.

This morning, city works crews, garbage packers and private contractors were atop the ski hill... dumping garbage and covering it with land-fill.

Residents of the area are up in arms and Ald. King Enright is attempting to rectify the matter...

The problem for the city is the objection by an estimated 120 residents in the area of the proposed ski hill on Montreal street.

The residents, many of whom turned out to hear debate on the issue last night, claim their view of the municipal golf course, Bell's Island and the waterfront will be blocked by the extreme height of the ski hill.

They do not object to the ski hill, only to its location (300 feet from some of their homes) and have suggested the city could move the hill to the east end of Belle Park drive, adjacent to Bell's Island.

Ald. Cook said the city has spent large sums of money and that money and time, plus plans for the nine-hole golf course, would be lost or stalled for a long period of time if the whole area has to be redesigned.

He pointed out that the original idea of forming the ski hill resulted from an effort to help the works department prolong the length of time it could use the present dumpsite...

... leading debate in favour of moving the hill nearer to Bell's Island, was Ald. Kenneth Matthews. He was supported by fellow Cataraqui Ward Ald. King Enright.

After putting up with city dump operations on their doorstep for 17 years, said Ald. Matthews, the Montreal street residents had been "promised the consolation prize" of the golf course, "but now they won't even be able to see it".

What actions do you think would be right, or fair, or just, in this situation?

(b) There may be cases of this kind much closer to your home than Kingston, Ontario. Are home-owners being forced to move to make way for freeways? Are parks being bulldozed or shade trees cut down? Examine such a case and analyse the nature of the conflict between individuals and society. Decide for yourself where the right lies, and provide reasons to support your view.

It may be that some of you see very clearly the similarities between an ecosystem and a city. Those who don't should take time to look for them. People and institutions are comparable to various parts of an ecosystem, and a city can be considered to be a kind of artificial ecosystem, quite probably subject to the same rules of operation as natural ecosystems. If the comparison between cities and natural ecosystems is valid, what sort of planning is needed to ensure the continued healthy survival of cities? How can we humans control the conflict between our dependencies and our desire to be independent?

5.4 Governments Are Interdependent

It is easy for individuals to blame governments for things that go wrong in the environment. It will usually be found that, the higher the level of government, and the farther away it is, the more likely it is that people will blame it. This may be related to the fact that local governments generally do pretty much what most people want done. Elected persons will undertake all sorts of projects but rarely will they commit political suicide by steadily displeasing a large number of voters. Also, when people lay blame on a local government, what they are really doing is blaming themselves. That is a hard thing to do. It is much easier to point the finger of accusation at the senior government members who are far away. The responsibility doesn't strike so close to home.

If you do not accept the notion that all our governments do, more or less, what most people want done, perhaps you can accept the proposition that governments are interdependent in the same sorts of ways that people are dependent on each other. The actions needed for the maintenance or restoration of environmental quality frequently involve a number of communities, and this means that various levels of government must act co-operatively.

CASE 11: A Tale of Three Cities

Three cities are located on the same river system. City A is farthest upstream, C is farthest downstream, and B lies in between. For many years the cities have been emptying raw sewage into the river without any apparent harm because the river ecosystem has been able to decompose the sewage with only a slight increase in the growth of water weeds and algae. Recently, the cities have been getting larger, and the river is no longer able to cope with the sewage. The situation has come to official notice because a large food-processing company wants to open a plant in City B. This would be great for the economy of B. It would also help A and C a little. The only difficulty is that the food-processing plant cannot use the river water. It is too dirty. Also, this company does not want to ask its employees to live in a community with such an unsafe water supply. Somehow, City B has to persuade City A to stop dumping raw sewage. Just to complicate the problem, imagine that at the same time City C complains to City B about the poor water quality due to City B's sewage.

Now, you are mayor of City B. You have the support of the city government for your policies. Write three letters: the first to the mayor of City A, enlisting the co-operation of his government in improving the quality of the river; the second to the president of the food-processing company, trying to keep him interested in placing a plant in your city; and the third to the mayor of City C, replying to his request that you install a complete sewage-processing system.

You can add to the interest of this exercise by working in three groups, each group acting as the government of one city. Elect a mayor, and check on his letter-writing. If there is a teacher of civics or history in your school who is especially interested in municipal government, he or she might be able to help.

A third possible variation is to make a case study of an actual, current situation in your area. For example, interprovincial or international co-operation (or lack of it) in controlling the pollution of boundary waters might be of interest.

You can see that co-operation between various governments holds both the highest promise and the greatest dangers for the environment. Consider two examples. First is the case of the city of Chicago, which has need of large quantities of water. The simplest method is to take water from Lake Michigan and to empty the used water into the Mississippi River system to the south. Careful study of a good topographic map makes the situation very clear. Here is a city government needing to draw on intercity, interstate, and international water resources. The governments of all of the Great Lakes states and provinces, as well as the governments of the United States and Canada, have to be involved. You can also see that without careful, honest study beforehand it would be dangerous to divert large amounts of water in this way.

A second example is the complex of problems surrounding economic development in the North. How can the resources of the North be used without hopelessly damaging this fragile environment? Our society is demanding oil from the Arctic. The oil companies have it. The consumers (including you and me and our governments) want to buy it. The governments concerned have to help them, or at least not hinder. At the same time, the Arctic ecosystems are especially vulnerable to pollution. A pipeline gives off heat, and will melt the permafrost. Caterpillar tractors leave permanent trails of damaged tundra (see Question 5, Chapter 2). Oil tankers have proven to be environmentally dangerous. How can governments act to regulate and control exploitation of the North so that its promise can be fulfilled on the one hand, and the quality of the environment sustained on the other?

5.5 Compromise

Someone has said that a compromise is the answer to a conflict that satisfies neither party. And you may have sensed that there is no answer but compromise to the conflicting demands that people make upon the environment. There are those who demand high-quality air, water, and land. There are those who really don't care what the environment is like as long as they can live and work in the manner they choose. Sometimes these two conflicting demands are made by the same person. It is interesting to watch an anti-pollution committee at work in a smoke-filled room.

There are other reasons for suspecting that compromise is necessary. In many of the problems described in this chapter, you will have found it difficult to reach a clear decision of what is right or just. There are two or more sides to most questions and an unsatisfying compromise may be the only possible resolution. It is often hard to find an absolutely right decision. There is probably no perfect environment for modern man. Think of as many examples as you can to support this idea.

There can only be improvement in environmental quality when individuals, institutions, and governments are prepared to give up some of their comforts and conveniences. Does this mean that our standard of living is higher than our ecosystem can support? Are we living beyond our environmental means? Or can improved technology, restraint, and compromise let us have both the good life and the good environment?

Questions

1. Figures 5:2 and 5:4 are placed in Chapter 5 but no mention is made of them anywhere in the chapter. To which section do you think each best belongs, and why?

2. Section 5.5 stresses the idea that compromises are the most likely way to solve our environmental problems. Perhaps you disagree. What arguments do you have to support your view?

3. Make a study of the use of salt on city streets in the winter. Where does the salt come from? Where does it go? What would people say, and what would they do, if the streets department stopped using salt?

4. The following air pollution table gives the average weights of common polluting substances released, or formed, when certain fuels are used normally.

Fuel used	*Average weight in lb. of substances released for each 1000 lb. of fuel used.*				
	Sulphur oxides	*Nitrogen oxides*	*Carbon mon-oxide*	*Other gases*	*Solids*
gasoline	21	62	4000	59	0.4
diesel fuel	19	94	—	37	125
garbage	5	2	—	—	12
fuel oil	300	14	—	—	2
fuel coal	20	4	—	—	100
natural gas	—	7	—	—	—

(a) If you wish to reduce air pollution, which fuels should be discouraged and which encouraged? Give reasons for your choices.

(b) Suppose that the most polluting fuels in the table were outlawed. How would your life be different?

5. You may have noticed that a precise definition of the word pollution has not been given. One of the reasons is that, in many cases, man-made pollution is simply the acceleration of a naturally occurring process. Now that you have thought about pollution in a variety of different ways, write a definition for the word. Compare your definition with those of your classmates. How can you tell if a definition is a good one or not?

APPENDIX

Taking Water Apart

One of the ways of learning about a thing is to take it apart and look at the pieces you get and the connections between them. You already know enough about water to begin the process of dissection mentally. For instance, you could surely tell the difference between sea water and the tap water from Kamloops, British Columbia, by simply holding each in your mouth for a moment. You could tell the difference between lake water and water from a swimming pool.

Obviously, it is not the water that is different in these cases, but rather the materials that the water has dissolved in it. If that is true, then we will have to be sure that we understand each other when we use the word "water". We will constantly have to ask: "Does this statement refer to the water itself, or to the stuff dissolved in the water, or to both?"

It is clear that people can easily distinguish certain types of watery solutions from each other. In almost every case, the solution is strong enough to be recognized by one of our senses. But if we wish to take water apart, it will be necessary to identify watery solutions that are *not* readily apparent to the senses. One of the several tools for doing this is a test of the ability of water to conduct an electric current. (If you have not done this before, Laboratory Activity A-1 below suggests ways for you to proceed with the test.) Another way of helping our senses to detect and identify watery solutions is to use various chemical tests, some of which are described in Chapter 2.

Laboratory Activity A-1
How well do water and watery solutions conduct electricity?

Several forms of apparatus have been devised to test whether or not liquids can conduct electricity. In every case, an electrical circuit containing a light bulb is set up. Part of the circuit is broken and two ends of bare wire stick out. (See Fig. A:1.)

CAUTION: The apparatus described could be dangerous. Be sure to discuss safety procedures with your teacher before attempting to set it up.

The two ends of wire may be dipped into the liquid to be tested. If the material between the ends of wire conducts electric current, the bulb can be expected to light up. (Of course, it is necessary to check to see that the bulb and the rest of the circuit are working.)

You may use an apparatus of the kind described to check

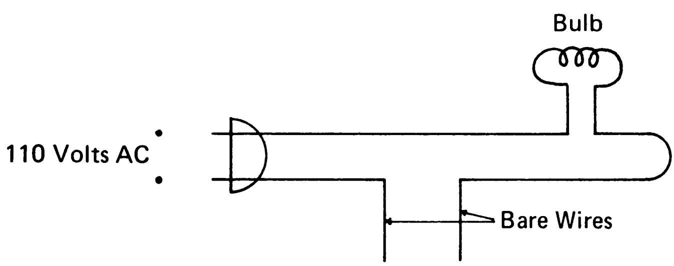

Figure A:1 Schematic diagram of an electric circuit for testing the conductivity of liquids.

the ability of a variety of waters to conduct electricity. It is wise to rinse the two bare testing-wires with reasonably pure (or distilled) water between each test.

There are many substances that could be tested: for example, a salt solution, tap water, soda pop, distilled water, a sugar solution, tea, saliva, an aspirin solution, dilute acid.

It should be possible for you to group the substances you test into two kinds: those that are apparently poor conductors of electricity and those that are good ones. One can tell the very good conductors from the weaker ones by observing how brightly the lamp lights. The substances may be divided into three or four groups on this basis.

Points to consider

1. What are some of the possible reasons for one solution conducting electricity and another one not conducting it?
2. How do you think substances such as carbon tetrachloride, turpentine, wood alcohol, or motor oil will behave in the test apparatus? How did they work?
3. Observing the brightness of a light bulb is not a very precise way of telling how much electricity is moving in the circuit. Find a better way.
4. How do various samples of polluted waters behave in the conductivity apparatus?

It is a widespread fallacy that water (absolutely pure water, that is) is a stable chemical known as H_2O. The formula implies that water is made up of little chunks (or grains, or molecules) each containing two atoms of hydrogen and one atom of oxygen. Our dissection of water so far fails to shed much light on this idea because it has dealt mainly with the effects caused by impurities in the water. This failure is easily corrected by following the procedures of the men who first studied the passage of electricity through watery solutions. The following laboratory activities outline effective methods of using electric current to take water apart.

Laboratory Activity A-2

What effect does electricity have on the water it passes through?

There is a variety of equipment suitable for investigating this question. A few kinds of apparatus are shown in Figure A:2. Despite the apparent differences, all of the equipment diagrammed operates on the same basic principles. The requirements are three: a source of direct current (either 6 or 12 volts — 12 volts is better) with wires and switches, a container of water with an appropriate impurity added, and finally a pair of inert electrodes to make electrical connection between the energy source and the solution. A laboratory power supply or a battery of dry cells can provide the electrical energy. Several suggestions for appropriate impurities are made in the following paragraphs.

The electrodes need to be *inert* in the sense that they should not react chemically with the solution being studied. Most electrodes are made of platinum, but carbon ones will work in most cases.

Remember that the idea is to try to take water apart by subjecting it to an electric current. By now, you may wonder why pure water is not used, but if you have done Laboratory Activity A-1 you will realize why that procedure will *not* work. Instead, we can achieve our purpose by putting a small amount of dilute sulphuric acid into the water first and then proceeding as suggested above. Watch the apparatus closely for signs of new substances being formed. You may detect a colour change, or bubbles of gas, or a faint odour. If any of these things happen, find out how to identify the new substances formed.

It may be difficult for you to interpret the results of this experiment. One of the complicating factors is the need to add the sulphuric acid to the water. However, it has been shown that the sulphuric acid itself remains the same during the experiment. Thus, any changes observed must be due to the breakdown of water.

The experience gained from observing similar reactions with watery solutions of substances other than sulphuric acid suggests that water exists in more forms than just molecules of hydrogen

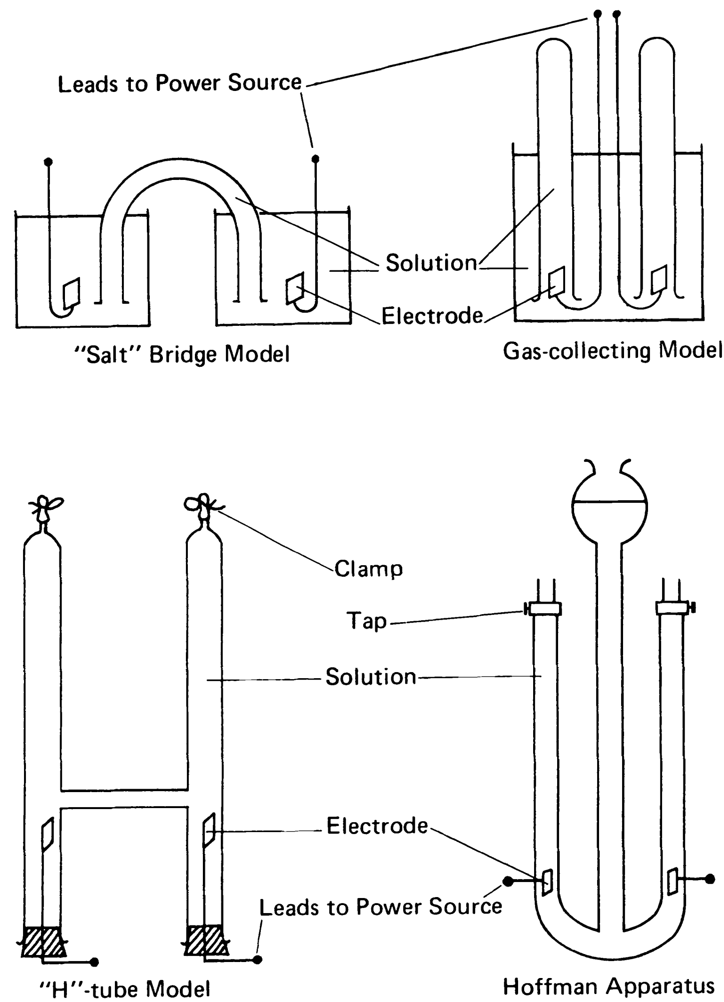

Figure A:2 Four different forms of apparatus used to study the effect of electricity upon solutions. In each type there are electrodes, connections to the D.C. voltage source, and a solution to be studied.

and oxygen atoms. One is like H_2O, and the other two are electrically active particles H^+ (called hydrogen-ion) and OH^- (called hydroxyl-ion). The three substances are related to each other as shown:

$$H^+ + OH^- \rightleftarrows H_2O$$

The symbolic formula means that some water molecules form one hydrogen-ion and one hydroxyl-ion each. It also means that one of each kind of ion can join together to form an electrically weaker water molecule.

The likelihood that pure water contains three substances, two of which are electrically active, is demonstrated by the electrolysis experiments. The description of those substances and how they interact, which is given here in the simplest form available, is useful in studying the nature of water pollution. In later years, some of you may encounter fuller explanations for the behaviour of water. For those who wish to pursue the matter further now, Laboratory Activity A-3 will be of interest.

It may also be instructive to use solutions other than very weak sulphuric acid and water. For example, a solution of common salt works well in the electrolysis apparatus.

There are three distinct experiments that can be done with salt solution. One uses plain salt and water. Another uses salt and water with the addition of a few drops of food colouring. The third is to add several drops of the acid-base indicator phenolphthalein to the salt solution. (The use of acid-base indicators is the subject of Section 2.3, Chapter 2.)

The effects of electrolysing the simple water and salt solution are difficult to grasp without learning a little about the chemistry of both salt and water. Since this doesn't have a direct connection with environmental pollution, it is not discussed here, although you and your teacher may find it of interest to pursue the subject. The explanation of the events in the cases of the food colouring and the phenolphthalein are more important. The existence of bleaching reactions and the matter of acid-base balance is important in the aquatic ecosystem.

Laboratory Activity A-3
What effect has the electric current on a salt solution?

Place a solution of sodium chloride and distilled water in an electrolysis apparatus, and turn on the energy supply. Look carefully at the electrodes for signs of new substances being

formed. Try to identify whatever new substances might be there.
How does the behaviour of the salt solution differ from that of dilute sulphuric acid?

Laboratory Activity A-4
More on the electrolysis of a salt solution

Before placing the salt solution in the apparatus, stir in a few drops of the acid-base indicator phenolphthalein (see Fig. 2:1 for a scale of colour changes). Then proceed with the usual electrolysis.

What additional evidence is there of a new substance being formed?

Phenolphthalein is colourless in acid and near neutral solutions. How could you check to determine whether both acids and bases are formed in the salt solution?

What happens if you tilt (or stir) the electrolysis apparatus so that the liquid around one electrode mixes with that around the other?

This experiment can also be done with other indicators, such as bromthymol blue.

Laboratory Activity A-5
Still more on the electrolysis of a salt solution

This time tint the sodium chloride solution with a food colouring dye and let the apparatus run. What happens to the dye? What causes the effect? To answer these questions you will have to research the details of the chemical changes that occur at the electrodes.

Titration

Laboratory Activity A-4 and Section 2.4 of Chapter 2 point to the use of the process of neutralization to measure the amount of an acid or a base in a solution. The method, called titration, is based on the idea that a certain amount of any acid (as H^+) will be sufficient to completely neutralize an equal amount of base (as OH^-).

Laboratory Activity A-6
An introduction to titration

Before you begin, your teacher will give you instructions and training in the use of a piece of apparatus called a burette. For this activity, each team of workers will require two burettes, beakers of appropriate sizes, stirring rods, suitable indicators (either phenolphthalein or bromthymol blue), and two solutions, one prepared by diluting 10 ml of 12M hydrochloric acid in about 100 ml of distilled water, and the other by dissolving about 10 gm of solid sodium hydroxide in 100 ml of water.

Load one burette with acid solution and the other burette with the base. Run 10 ml of one solution into a clean, dry beaker, being sure to record the volume used as accurately as the burette will allow. Put a drop of indicator into the sample and then titrate by adding the opposite solution to the beaker, while stirring, until the indicator shows neutrality (pH7, in this case). You may have to repeat this procedure a few times until you learn not to add too much acid or base from the second burette.

Now that you have a clear idea of the volume of the second solution needed to neutralize your sample of the first, predict the volume needed to neutralize twice as much of the first. Once you have made your prediction, try it and see how it works.

Suppose you took 5 ml of the second solution and titrated against the first. What volume would be required? Test your answer.

Suppose the acid were half as "strong", that is, diluted to twice its present volume. What volume of the acid solution would now be needed to neutralize 10 ml of your basic solution? Try it and see.

You may wish to practise titration by working with unknown samples. Your teacher may make up some acids of unknown strengths for practice purposes. One can titrate samples of natural water or industrial waste collected in your community. You should attempt to use your titration skill in an accurate measurement of dissolved oxygen. (See the Winkler Test on page 111.)

If you have followed the titration work so far, some things will be clear and other things may be very confused. It should be clear from Laboratory Activity A-6 that the *volumes* of an acid solution and a basic solution that just neutralize each other are *not* necessarily equal. This may conflict in your mind with the statement made just before the laboratory activity, that the *amounts* of acid and base that neutralize each other are equal.

The catch lies in the distinction between the words "volume of solution" and "amount of acid or base". It takes a large volume of a very dilute acid to contain the same number of excess hydrogen-ions as a small volume of a much stronger acid. It takes a greater *volume* of dilute base to hold the same *amount* of base (number of excess hydroxyl-ions) that a strong base does. Mastery of these ideas requires an understanding of the notion of *concentration*. Concentration is the word used to describe the *quantity of material found in a unit of volume.*

The quantity of acid or base present in any sample solution depends on two things: the volume of the sample, and the concentration of the solution. The more concentrated the solution, the more acid or base is present. The smaller the volume, the less acid or base is present if the concentration is constant. Your laboratory work has shown that doubling the volume results in twice as much acid or base, and half the concentration means half as much acid or base in a given volume. This means that a simple arithmetical expression can be used to put these ideas together.

$$\text{amount of acid or base} = \text{volume} \times \text{concentration}$$

This relationship is especially useful when the concentration is expressed in a certain way — as *normality*. It goes beyond the scope of this book to work with normality, but should you want to learn more about it, many textbooks of general chemistry will be helpful.

Questions on Titration

1. If a 10.0 ml water sample is just neutralized by 20.0 ml of base, what is the relative concentration of the two solutions?
2. A standard laboratory base is 2.3 times as concentrated as an acidic solution being tested. What volume of base will neutralize 50 ml of the acidic solution?
3. A basic solution is 1.5 times as concentrated as an acidic solution. What is the ratio of volumes required for neutralization?
4. In a titration, three samples, each being 15.0 ml of acid, were titrated against a standardized base. The results were 24.9 ml, 25.0 ml, and 25.0 ml of base added. How does the concentration of acid compare to that of the standardized base?

Preparing Bicarbonate Indicator

The special bicarbonate indicator solution is prepared first as a stock solution by dissolving 0.1 gm of cresol red and 0.2 gm of thymol blue in 20 ml of alcohol and by adding this dye preparation to 900 ml of distilled water to which you have previously added 0.84 gm of reagent-grade sodium bicarbonate. The whole mixture should then be made up to a volume of 1 litre by adding distilled water.

The stock solution is too strong for direct use. To get the final indicator solution, dilute a portion of the stock by a factor of 10. For example, measure out 50 ml of stock solution into a 500-ml volumetric flask and fill the flask to the 500-ml line with distilled water.

The solution is ready to use if it is a red colour. If the colour is yellow or orange, bubble some *air* (not your breath) through the solution until it turns red. An aquarium air pump will do the job. Incidentally, this indicator will also work well in Laboratory Activity 3-1 of Chapter 3.

The Winkler Test for Dissolved Oxygen

The most widely recognized measurement of dissolved oxygen is called the Winkler method after the man who developed it. This is a very sensitive technique and is easily spoiled by contamination of the sample with oxygen of the air. If you do not use a container especially designed for the purpose (such as a BOD bottle) then you must fill the containers gently from the bottom to overflowing, being careful to exclude air bubbles, and stopper them tightly. If you are collecting water samples in the field, the first parts of the test should be done immediately. The samples will then keep until the measurement process can be completed back in the laboratory.

The chemicals required are available in at least three packages. One is in a kit form provided as part of the Educational Module on Environmental Pollution available from Ward's Natural Science Establishment Inc. It has the advantage of having a simplified final titration. A second alternative is to use dry chemicals. These can be obtained from the Hach Chemical Company of Ames, Iowa, dispensed in plastic pillows of just the required size. The third method is to enlist the help of a chemistry teacher or a senior student and make up the solutions yourself.

The method is described in the following laboratory activity.

Laboratory Activity A-7
How much oxygen is in a water sample?

1. Collect a water sample (250 ml).
2. Add 2 ml of manganese (ous) sulphate solution (made by putting 368 gm of solid manganese (ous) sulphate into 1 litre of solution).
3. Add 2 ml of basic potassium iodide solution (made by mix-

ing 150 gm of potassium iodide and 500 gm of sodium hydroxide to make 1 litre of solution).

4. Combine the chemicals well by gently inverting or swirling the vessel. A rather fluffy solid will form, which may be more or less brownish in colour. Allow the solid to settle a little and then dissolve it by adding 2 ml of concentrated sulphuric acid.
   (THE ABOVE STEPS MAY BE DONE IN THE FIELD)
5. In the laboratory, the sample may be handled without fear of air contamination. Add about 2 ml of commercial starch indicator solution.
6. Titrate the sample, using a solution of sodium thiosulphate. (The 0.025 N solution is prepared by making 6.2 gm of the solid substance up into 1 litre of solution. It must be freshly prepared for use or else preserved by adding 5 ml of chloroform.) *The end point of the titration comes when the blue colour of the starch indicator solution first disappears permanently.*

   You will note that this is not an acid-base titration of the kind discussed in Section 2.4 of Chapter 2 and in the section on Titration in the earlier part of the Appendix. However, the principle and the techniques are essentially the same.
7. The volume of sodium thiosulphate solution used, in ml, multiplied by two, gives the oxygen content of the water in parts per million (ppm).

When you have mastered the technique you have chosen to use for the Winkler test, you will be able to determine quickly and accurately the oxygen levels in any water sample that interests you. This ability will be especially useful in the laboratory activities of Chapter 3.

Measuring Primary Productivity

A common method of measuring total photosynthesis is to divide a water sample containing active plants (algae or Elodea) as evenly as possible between two BOD bottles. One of the bottles is the normal, colourless glass kind, but the interior of the other is made dark by wrapping the bottle in aluminum foil or friction tape.

The bottles are left in the light for a measured time interval — usually from six to twenty-four hours, depending on the amount of plant material in the water. Then the oxygen content in each bottle is measured by the Winkler method.

The experiment will provide three measurements: the amount of dissolved oxygen in the light bottle (L_{OX} in ppm), the amount of dissolved oxygen in the dark bottle (D_{OX} in ppm) and the time duration of the experiment (T in hrs).

Now, you may either insert the numbers into the formula that follows, or follow the detailed reasoning that supports the use of the formula for an estimate of total photosynthesis. For those who will accept the formula for direct use, without proof, here it is:

$$\text{total photosynthesis} = .258 \times \frac{L_{ox} - D_{ox}}{T}$$

The solution to this equation gives the *number of milligrams of carbon fixed in the plants per litre of water per hour*. Thus the unit for the formula is expressed as mgm carbon/l water/hr. Details of the development of the formula are to be found in the paragraphs immediately following this experiment.

There are several variations of this basic experiment. One is to use water collected from a local pond or stream, together with whatever microscopic plants and animals happen to be there. In this case, the work can lead to an estimate of the possible productivity in the water at the sampling sites. (If the water taken does not contain many plant cells, the time for the experiment may have to be extended to forty-eight hours.)

Another variation is to place a vigorous water plant, such as Elodea, in the water samples. In this case, the time may be shortened and the final results will need careful interpretation, since the calculation yields an answer that assumes a uniform distribution of the plants used throughout a natural body of water. When you add a single, specialized plant species, you weaken the assumption.

Still another variation is to expose the light and dark bottles in the location from which the water samples are taken. For example, if a water sample is taken half a metre below the surface of a pond, suspend the two bottles at the same depth in the pond. In this way the light bottle will get its "normal" amount of light, and the temperature will be "normal", too. In this case, let the experiment run for twenty-four hours.

In the experiment we are using the release of oxygen by producers as a way of estimating the actual amount of new plant material they form. This is expressed in terms of the weight of carbon fixed. Two problems must be solved before this can be done. The first, already mentioned, is that oxygen production in the light bottle is the *net* result of the *total* photosynthetic output *minus* the respiratory consumption.

The second difficulty involves conversion of the figures obtained from the Winkler reaction in ppm oxygen into an expression of the weight of carbon assimilated by the plants. The formula given above helps to overcome both difficulties.

Note that it is possible to substitute mgm oxygen/l for ppm oxygen, since 1 litre of water weighs very nearly a million times as much as does 1 mgm. Thus the measurement L_{OX} in ppm also gives us a weight (in mgm) of oxygen per litre of water. Note, too, that L_{OX} is made up of three components: the original amount of oxygen in the water, the new oxygen added by photosynthesis, and the oxygen *subtracted* from the water by respiration. Thus,

$$L_{OX} = \begin{matrix}\text{original}\\\text{oxygen}\end{matrix} + \begin{matrix}\text{total}\\\text{photosynthetic}\\\text{production}\end{matrix} - \begin{matrix}\text{respiratory}\\\text{uptake}\end{matrix}$$

In the same way, D_{OX} tells us the original amount of oxygen in the water minus that used by the organisms respiring in the dark:

$$D_{OX} = \text{original oxygen} - \begin{matrix}\text{respiratory}\\\text{uptake}\end{matrix}$$

The formula given in the laboratory activity has the expression ($L_{OX} - D_{OX}$). If we perform this operation of subtraction,

$$L_{ox} = \text{original oxygen} + \text{total photosynthetic production} - \text{respiratory uptake}$$

subtract

$$D_{ox} = \text{original oxygen} - \text{respiratory uptake}$$

$$(L_{ox} - D_{ox}) = 0 + \text{total photosynthetic production} + 0$$

all terms cancel each other except total photosynthetic production.

Another problem involved the conversion of the oxygen production in mgm/l to the amount of carbon gained by the plants. This is done by applying arithmetic to the chemical equation for photosynthesis. In the simplest case, the chemical equation states that for every milligram of oxygen released, there are 0.375 mgm of carbon fixed.

A more realistic equation, based on experiments with algae, shows that each milligram of oxygen released represents 0.258 mgm of carbon fixed.

Thus, the formula multiplies total oxygen production by 0.258 in order to yield the weight of carbon.

The experiment with the light bottle and the dark bottle provides a useful estimate of the primary productivity of natural waters and the plants they contain. But the experiment has a number of pitfalls that should be considered.

How do you know the temperatures in the two bottles were the same? Why would it matter if they were not?

How do you know that respiration in the light bottle goes on at the same speed as in the dark bottle? Perhaps light speeds up (or slows down) respiration.

What are the possible effects of consumers (such as zooplankton) and of decomposers (such as bacteria) upon the results?

How reliable is the number 0.258? What assumptions went into the generating of that number?

To what extent is the experiment valid for different species of producers?

FURTHER READING

There are hundreds of books and pamphlets dealing with the environment and with pollution. This list names only a few that relate rather closely to the themes of the text.

D. E. Abrahamson, *Environmental Cost of Electric Power.* Scientists' Institute for Public Information, 1970.

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