

BARRY COMMONER

The Four Laws of Ecology

[1971]

BARRY COMMONER (1917–2012), a leading ecologist and environmental activist, and one of the founders of the environmental movement in the United States, was born in Brooklyn, New York. He studied zoology at Columbia University as an undergraduate and then attended Harvard University, where he received a Ph.D. in 1941. After a short stint in the army during World War II, he joined the faculty of Washington University in St. Louis, where he taught courses in botany and plant physiology for more than thirty years.

Commoner combined academic research with political activism throughout his career. In the 1950s, he became a vocal opponent of above-ground nuclear testing, which the United States and the Soviet Union conducted during the Cold War, and which he saw as having an extremely negative effect on the world's ecosystems. He also wrote extensively on the connection between poverty and overpopulation. Unlike Garrett Hardin (p. 344), who believed that wealthy nations should refuse to give even minimal food aid to poorer, overpopulated countries, Commoner believed that poverty caused overpopulation and that industrialized nations could only address the root of the problem by radically redistributing the world's wealth.

In 1979, Commoner founded the Citizens Party, an organization that he hoped would serve as the political arm of the environmental movement. In 1980, he ran for president of the United States under the party's banner, receiving more than 200,000 votes and becoming the first minor-party candidate to qualify for federal matching funds. After the election, Commoner returned to his native New York City and spent the rest of his career at Queens College, where he was still listed as a senior scientist when he died in 2012 at the age of ninety-five.

Commoner is best known as one of the founders of the science of ecology, or the study of the ways that different natural systems are connected to each other. His bestselling book *The Closing Circle* (1971) has become a standard reference point in that field. In this book, he argues that the laws of ecology are as absolute and inflexible as the laws of physics and that the nations of the world must align their policies with those laws or pay a steep price. The example presented here, "The Four Laws of Ecology," offers four ironclad principles that, Commoner believes, should become the basis of all economic and social policy.

To survive on the earth, human beings require the stable, continuing existence of a suitable environment. Yet the evidence is overwhelming that the way in which we now live on the earth is driving its thin, life-supporting skin, and ourselves with it,

to destruction. To understand this calamity, we need to begin with a close look at the nature of the environment itself. Most of us find this a difficult thing to do, for there is a kind of ambiguity in our relation to the environment. Biologically, human beings *participate* in the environmental system as subsidiary parts of the whole. Yet, human society is designed to *exploit* the environment as a whole, to produce wealth. The paradoxical role we play in the natural environment—at once participant and exploiter—distorts our perception of it.

Among primitive people, a person is seen as a dependent part of nature, a frail reed in a harsh world governed by natural laws that must be obeyed if he is to survive. Pressed by this need, primitive peoples can achieve a remarkable knowledge of their environment. The African Bushman¹ lives in one of the most stringent habitats on earth; food and water are scarce, and the weather is extreme. The Bushman survives because he has an incredibly intimate understanding of this environment. A Bushman can, for example, return after many months and miles of travel to find a single underground tuber, noted in his previous wanderings, when he needs it for his water supply in the dry season.

We who call ourselves advanced seem to have escaped from this kind of dependence on the environment. The Bushman must squeeze water from a searched-out tuber; we get ours by the turn of a tap. Instead of trackless terrain, we have the grid of city streets. Instead of seeking the sun's heat when we need it, or shunning it when it is too strong, we warm and cool ourselves with man-made machines. All this leads us to believe that we have made our own environment and no longer depend on the one provided by nature. In the eager search for the benefits of modern science and technology we have become enticed into a nearly fatal illusion: that through our machines we have at last escaped from dependence on the natural environment.

A good place to experience this illusion is a jet airplane. Safely seated on a plastic cushion, carried in a winged aluminum tube, streaking miles above the earth, through air nearly thin enough to boil the blood, at a speed that seems to make the sun stand still, it is easy to believe that we have conquered nature and have escaped from the ancient bondage to air, water, and soil.

But the illusion is easily shattered, for like the people it carries, the airplane is itself a creature of the earth's 'environment'. Its engines burn fuel and oxygen produced by the earth's green plants. Traced a few steps back, every part of the craft is equally dependent on the environment. The steel came from smelters fed with coal, water, and oxygen—all nature's products. The aluminum was refined from ore using electricity, again produced by combustion of fuel and oxygen or generated by falling water. For every pound of plastic in the plane's interior, we must reckon

1. **African Bushman:** a member of one of several hunter-gatherer tribes in the Southern region of Africa. This term is now considered to be pejorative and is normally replaced with "San people" in academic writing.

that some amount of coal was needed to produce the power used to manufacture it. For every manufactured part, gallons of pure water were used. Without the earth's natural environmental constituents—oxygen, water, fuel—the airplane, like man, could not exist.

The environment makes up a huge, enormously complex living machine that forms a thin dynamic layer on the earth's surface, and every human activity depends on the integrity and the proper functioning of this machine. Without the photosynthetic activity of green plants, there would be no oxygen for our engines, smelters, and furnaces, let alone support for human and animal life. Without the action of the plants, animals, and microorganisms that live in them, we could have no pure water in our lakes and rivers. Without the biological processes that have gone on in the soil for thousands of years, we would have neither food crops, oil, nor coal. This machine is our biological capital, the basic apparatus on which our total productivity depends. If we destroy it, our most advanced technology will become useless and any economic and political system that depends on it will founder. The environmental crisis is a signal of this approaching catastrophe. . . .

In broad outline, these are the environmental cycles which govern the behavior of the three great global systems: the air, the water, and the soil. Within each of them live many thousands of different species of living things. Each species is suited to its particular environmental niche, and each, through its life processes, affects the physical and chemical properties of its immediate environment.

Each living species is also linked to many others. These links are bewildering in their variety and marvelous in their intricate detail. An animal, such as a deer may depend on plants for food; the plants depend on the action of soil bacteria for their nutrients; the bacteria in turn live on the organic wastes dropped by the animal on the soil. At the same time, the deer is food for the mountain lion. Insects may live on the juices of plants or gather pollen from their flowers. Other insects suck blood from animals. Bacteria may live on the internal tissues of animals and plants. Fungi degrade the bodies of dead plants and animals. All this, many times multiplied and organized species by species in intricate, precise relationships, makes up the vast network of life on the earth.

The science that studies these relationships and the processes linking each living thing to the physical and chemical environment is *ecology*. It is the science of planetary housekeeping. For the environment is, so to speak, the house created on the earth by living things for living things. It is a young science and much of what it teaches has been learned from only small segments of the whole network of life on the earth. Ecology has not yet explicitly developed the kind of cohesive, simplifying generalizations exemplified by, say, the laws of physics. Nevertheless there are a number of generalizations that are already evident in what we now know about the ecosphere and that can be organized into a kind of informal set of "laws of ecology." These are described in what follows.

The First Law of Ecology: Everything Is Connected to Everything Else

Some of the evidence that leads to this generalization has already been discussed. It reflects the existence of the elaborate network of interconnections in the ecosphere: among different living organisms, and between populations, species, and individual organisms and their physicochemical surroundings. 10

The single fact that an ecosystem consists of multiple interconnected parts, which act on one another, has some surprising consequences. Our ability to picture the behavior of such systems has been helped considerably by the development, even more recent than ecology, of the science of cybernetics. We owe the basic concept, and the word itself, to the inventive mind of the late Norbert Wiener.²

The word "cybernetics" derives from the Greek word for helmsman; it is concerned with cycles of events that steer, or govern, the behavior of a system. The helmsman is part of a system that also includes the compass, the rudder, and the ship. If the ship veers off the chosen compass course, the change shows up in the movement of the compass needle. Observed and interpreted by the helmsman this event determines a subsequent one: the helmsman turns the rudder, which swings the ship back to its original course. When this happens, the compass needle returns to its original, on-course position and the cycle is complete. If the helmsman turns the rudder too far in response to a small deflection of the compass needle, the excess swing of the ship shows up in the compass—which signals the helmsman to correct his overreaction by an opposite movement. Thus the operation of this cycle stabilizes the course of the ship.

In quite a similar way, stabilizing cybernetic relations are built into an ecological cycle. Consider, for example, the fresh-water ecological cycle: fish—organic waste—bacteria of decay—inorganic products—algae—fish. Suppose that due to unusually warm summer weather there is a rapid growth of algae. This depletes the supply of inorganic nutrients so that two sectors of the cycle, algae and nutrients, are out of balance, but in opposite directions. The operation of the ecological cycle, like that of the ship, soon brings the situation back into balance. For the excess in algae increases the ease with which fish can feed on them; this reduces the algal population, increases fish waste production, and eventually leads to an increased level of nutrients when the waste decays. Thus, the levels of algae and nutrients tend to return to their original balanced position.

In such cybernetic systems the course is not maintained by rigid control, but flexibly. Thus the ship does not move unwaveringly on its path, but actually follows it in a wavelike motion that swings equally to both sides of the true course. The frequency of these swings depends on the relative speeds of the various steps in the cycle, such as the rate at which the ship responds to the rudder.

2. Norbert Wiener: American mathematician and philosopher (1894–1964).

Ecological systems exhibit similar cycles, although these are often obscured by the effects of daily or seasonal variations in weather and environmental agents. The most famous examples of such ecological oscillations are the periodic fluctuations of the size of fur-bearing animal populations. For example, from trapping records in Canada it is known that the populations of rabbits and lynx follow ten-year fluctuations. When there are many rabbits the lynx prosper; the rising population of lynx increasingly ravages the rabbit population, reducing it; as the latter become scarce, there is insufficient food to support the now numerous lynx; as the lynx begin to die off, the rabbits are less fiercely hunted and increase in number. And so on. These oscillations are built into the operation of the simple cycle, in which the lynx population is positively related to the number of rabbits and the rabbit population is negatively related to the number of lynx.

In such an oscillating system there is always the danger that the whole system will collapse when an oscillation swings so wide of the balance point that the system can no longer compensate for it. Suppose, for example, in one particular swing of the rabbit—lynx cycle, the lynx manage to eat *all* the rabbits (or, for that matter, all but one). Now the rabbit population can no longer reproduce. As usual, the lynx begin to starve as the rabbits are consumed; but this time the drop in the lynx population is not followed by an increase in rabbits. The lynx then die off. The entire rabbit—lynx system collapses.

This is similar to the ecological collapse which accompanies what is called "eutrophication."³ If the nutrient level of the water becomes so high as to stimulate the rapid growth of algae, the dense algal population cannot be long sustained because of the intrinsic limitations of photosynthetic efficiency. As the thickness of the algal layer in the water increases, the light required for photosynthesis that can reach the lower parts of the algal layer becomes sharply diminished, so that any strong overgrowth of algae very quickly dies back, releasing organic debris. The organic matter level may then become so great that its decay totally depletes the oxygen content of the water. The bacteria of decay then die off, for they must have oxygen to survive. The entire aquatic cycle collapses.

The dynamic behavior of a cybernetic system—for example, the frequency of its natural oscillations, the speed with which it responds to external changes, and its over-all rate of operation—depends on the relative rates of its constituent steps. In the ship system, the compass needle swings in fractions of a second; the helmsman's reaction takes some seconds; the ship responds over a time of minutes. These different reaction times interact to produce, for example, the ship's characteristic oscillation frequency around its true course.

In the aquatic ecosystem, each biological step also has a characteristic reaction time, which depends on the metabolic and reproductive rates of the organisms involved. The time to produce a new generation of fish may be some months; of algae,

3. **Eutrophication:** the biological process in which the dissolved nutrients in a body of water stimulate the growth of plant life, which, in turn, depletes the amount of dissolved oxygen.

a matter of days; decay bacteria can reproduce in a few hours. The metabolic rates of these organisms—that is, the rates at which they use nutrients, consume oxygen, or produce waste—is inversely related to their size. If the metabolic rate of a fish is 1, the algal rate is about 100, and the bacterial rate about 10,000.

If the entire cyclical system is to remain in balance, the over-all rate of turnover must be governed by the slowest step—in this case, the growth and metabolism of the fish. Any external effect that forces part of the cycle to operate faster than the over-all rate leads to trouble. So, for example, the rate of waste production by fish determines the rate of bacterial decay and the rate of oxygen consumption due to that decay. In a balanced situation, enough oxygen is produced by the algae and enters from the air to support the decay bacteria. Suppose that the rate at which organic waste enters the cycle is increased artificially, for example, by dumping sewage into the water. Now the decay bacteria are supplied with organic waste at a much higher level than usual; because of their rapid metabolism they are able to act quickly on the increased organic load. As a result, the rate of oxygen consumption by the decay bacteria can easily exceed the rate of oxygen production by the algae (and its rate of entry from the air) so that the oxygen level goes to zero and the system collapses. Thus, the rates of the separate processes in the cycle are a natural state of balance which is maintained only so long as there are no external intrusions on the system. When such an effect originates outside the cycle, it is not controlled by the self-governing cyclical relations and is a threat to the stability of the whole system.

Ecosystems differ considerably in their rate characteristics and therefore vary a great deal in the speed with which they react to changed situations or approach the point of collapse. For example, aquatic ecosystems turn over much faster than soil ecosystems. Thus, an acre of richly populated marine shoreline or an acre of fish pond produces about seven times as much organic material as an acre of alfalfa annually. The slow turnover of the soil cycle is due to the rather low rate of one of its many steps—the release of nutrient from the soil's organic store, which is very much slower than the comparable step in aquatic systems.

The amount of stress which an ecosystem can absorb before it is driven to collapse is also a result of its various interconnections and their relative speeds of response. The more complex the ecosystem, the more successfully it can resist a stress. For example, in the rabbit-lynx system, if the lynx had an alternative source of food they might survive the sudden depletion of rabbits. In this way, branching—which establishes alternative pathways—increases the resistance of an ecosystem to stress. Most ecosystems are so complex that the cycles are not simple circular paths, but are crisscrossed with branches to form a network or a fabric of interconnections. Like a net, in which each knot is connected to others by several strands, such a fabric can resist collapse better than a simple, unbranched circle of threads—which if cut anywhere breaks down as a whole. Environmental pollution is often a sign that ecological links have been cut and that the ecosystem has been artificially simplified and made more vulnerable to stress and to final collapse.

The feedback characteristics of ecosystems result in amplification and intensification processes of considerable magnitude. For example, the fact that in food chains small organisms are eaten by bigger ones and the latter by still bigger ones inevitably results in the concentration of certain environmental constituents in the bodies of the largest organisms at the top of the food chain. Smaller organisms always exhibit much higher metabolic rates than larger ones, so that the amount of their food which is oxidized relative to the amount incorporated into the body of the organism is thereby greater. Consequently, an animal at the top of the food chain depends on the consumption of an enormously greater mass of the bodies of organisms lower down in the food chain. Therefore, any nonmetabolized material present in the lower organisms of this chain will become concentrated in the body of the top one. Thus, if the concentration of DDT⁴ (which is not readily metabolized) in the soil is 1 unit, earthworms living in the soil will achieve a concentration of from 10 to 40 units, and in woodcocks feeding on the earthworms the DDT level will rise to about 200 units.

All this results from a simple fact about ecosystems—everything is connected to everything else: the system is stabilized by its dynamic self-compensating properties; these same properties, if overstressed, can lead to a dramatic collapse; the complexity of the ecological network and its intrinsic rate of turnover determine how much it can be stressed, and for how long, without collapsing; the ecological network is an amplifier, so that a small perturbation in one place may have large, distant, long-delayed effects.

The Second Law of Ecology: Everything Must Go Somewhere

This is, of course, simply a somewhat informal restatement of a basic law of physics—that matter is indestructible. Applied to ecology, the law emphasizes that in nature there is no such thing as “waste.” In every natural system, what is excreted by one organism as waste is taken up by another as food. Animals release carbon dioxide as a respiratory waste; this is an essential nutrient for green plants. Plants excrete oxygen, which is used by animals. Animal organic wastes nourish the bacteria of decay. Their wastes, inorganic materials such as nitrate, phosphate, and carbon dioxide, become algal nutrients.

A persistent effort to answer the question “Where does it go?” can yield a surprising amount of valuable information about an ecosystem. Consider, for example, the fate of a household item which contains mercury—a substance with environmental effects that have just recently surfaced. A dry-cell battery containing mercury is purchased, used to the point of exhaustion, and then “thrown out.” But where does it really go? First it is placed in a container of rubbish; this is collected and taken to an incinerator. Here the mercury is heated; this produces mercury vapor which is

4. DDT: Dichlorodiphenyltrichloroethane, a common pesticide discussed in Rachel Carson's *Silent Spring* (p. 328).

emitted by the incinerator stack, and mercury vapor is toxic. Mercury vapor is carried by the wind, eventually brought to earth in rain or snow. Entering a mountain lake, let us say, the mercury condenses and sinks to the bottom. Here it is acted on by bacteria which convert it to methyl mercury. This is soluble and taken up by fish; since it is not metabolized, the mercury accumulates in the organs and flesh of the fish. The fish is caught and eaten by a man and the mercury becomes deposited in his organs, where it might be harmful. And so on.

This is an effective way to trace out an ecological path. It is also an excellent way to counteract the prevalent notion that something which is regarded as useless simply "goes away" when it is discarded. Nothing "goes away"; it is simply transferred from place to place, converted from one molecular form to another, acting on the life processes of any organism in which it becomes, for a time, lodged. One of the chief reasons for the present environmental crisis is that great amounts of materials have been extracted from the earth, converted into new forms, and discharged into the environment without taking into account that "everything has to go somewhere." The result, too often, is the accumulation of harmful amounts of material in places where, in nature, they do not belong.

The Third Law of Ecology: Nature Knows Best

In my experience this principle is likely to encounter considerable resistance, for it appears to contradict a deeply held idea about the unique competence of human beings. One of the most pervasive features of modern technology is the notion that it is intended to "improve on nature"—to provide food, clothing, shelter, and means of communication and expression which are superior to those available to man in nature. Stated baldly, the third law of ecology holds that any major man-made change in a natural system is likely to be *detrimental* to that system. This is a rather extreme claim; nevertheless I believe it has a good deal of merit if understood in a properly defined context.

I have found it useful to explain this principle by means of an analogy. Suppose you were to open the back of your watch, close your eyes, and poke a pencil into the exposed works. The almost certain result would be damage to the watch. Nevertheless, this result is not *absolutely* certain. There is some finite possibility that the watch was out of adjustment and that the random thrust of the pencil happened to make the precise change needed to improve it. However, this outcome is exceedingly improbable. The question at issue is: why? The answer is self-evident: there is a very considerable amount of what technologists now call "research and development" (or, more familiarly, "R & D") behind the watch. This means that over the years numerous watchmakers, each taught by a predecessor, have tried out a huge variety of detailed arrangements of watch works, have discarded those that are not compatible with the over-all operation of the system and retained the better features. In effect,

the watch mechanism, as it now exists, represents a very restricted selection, from among an enormous variety of possible arrangements of component parts, of a singular organization of the watch works. Any random change made in the watch is likely to fall into the very large class of inconsistent, or harmful, arrangements which have been tried out in past watch-making experience and discarded. One might say, as a law of watches, that "the watchmaker knows best."

There is a close, and very meaningful, analogy in biological systems. It is possible to induce a certain range of random, inherited changes in a living thing by treating it with an agent, such as x-irradiation, that increases the frequency of mutations. Generally, exposure to x-rays increases the frequency of all mutations which have been observed, albeit very infrequently, in nature and can therefore be regarded as possible changes. What is significant, for our purpose, is the universal observation that when mutation frequency is enhanced by x-rays or other means, nearly all the mutations are harmful to the organisms and the great majority so damaging as to kill the organism before it is fully formed.

In other words, like the watch, a living organism that is forced to sustain a random change in its organization is almost certain to be damaged rather than improved. And in both cases, the explanation is the same—a great deal of "R & D." In effect there are some two to three billion years of "R & D" behind every living thing. In that time, a staggering number of new individual living things have been produced, affording in each case the opportunity to try out the suitability of some random genetic change. If the change damages the viability of the organism, it is likely to kill it before the change can be passed on to future generations. In this way, living things accumulate a complex organization of compatible parts; those possible arrangements that are not compatible with the whole are screened out over the long course of evolution. Thus, the structure of a present living thing or the organization of a current natural ecosystem is likely to be "best" in the sense that it has been so heavily screened for disadvantageous components that any new one is very likely to be worse than the present ones.

This principle is particularly relevant to the field of organic chemistry. Living things are composed of many thousands of different organic compounds, and it is sometimes imagined that at least some of these might be improved upon if they were replaced by some man-made variant of the natural substance. The third law of ecology suggests that the artificial introduction of an organic compound that does not occur in nature, but is man-made and is nevertheless active in a living system, is very likely to be harmful.

This is due to the fact that the varieties of chemical substances actually found in living things are vastly more restricted than the possible varieties. A striking illustration is that if one molecule each of all the possible types of proteins were made, they would together weigh more than the observable universe. Obviously there are a fantastically large number of protein types that are not made by living cells. And on the basis of the foregoing, one would reason that many of these possible protein types were once formed in some particular living things, found to be harmful, and rejected through the death of the experiment. In the same way, living cells synthesize fatty acids (a type of organic molecule that contains carbon chains of various lengths) with even-

numbered carbon chain lengths (i.e., 4, 6, 8, etc., carbons), but no fatty acids with odd-numbered carbon chain lengths. This suggests that the latter have once been tried out and found wanting. Similarly, organic compounds that contain attached nitrogen and oxygen atoms are singularly rare in living things. This should warn us that the artificial introduction of substances of this type would be dangerous. This is indeed the case, for such substances are usually toxic and frequently carcinogenic. And, I would suppose from the fact that DDT is nowhere found in nature, that somewhere, at some time in the past, some unfortunate cell synthesized this molecule—and died.

One of the striking facts about the chemistry of living systems is that for every organic substance produced by a living organism, there exists, somewhere in nature, an enzyme capable of breaking that substance down. In effect, no organic substance is synthesized unless there is provision for its degradation; recycling is thus enforced. Thus, when a new man-made organic substance is synthesized with a molecular structure that departs significantly from the types which occur in nature, it is probable that no degradative enzyme exists, and the material tends to accumulate.

Given these considerations, it would be prudent, I believe, to regard every man-made organic chemical *not* found in nature which has a strong action on any one organism as potentially dangerous to other forms of life. Operationally, this view means that all man-made organic compounds that are at all active biologically ought to be treated as we do drugs, or rather as we *should* treat them—prudently, cautiously. Such caution or prudence is, of course, impossible when billions of pounds of the substance are produced and broadly disseminated into the ecosystem where it can reach and affect numerous organisms not under our observation. Yet this is precisely what we have done with detergents, insecticides, and herbicides. The often catastrophic results lend considerable force to the view that “Nature knows best.”

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The Fourth Law of Ecology: There Is No Such Thing as a Free Lunch

In my experience, this idea has proven so illuminating for environmental problems that I have borrowed it from its original source, economics. The “law” derives from a story that economists like to tell about an oil-rich potentate who decided that his new wealth needed the guidance of economic science. Accordingly he ordered his advisers, on pain of death, to produce a set of volumes containing all the wisdom of economics. When the tomes arrived, the potentate was impatient and again issued an order—to reduce all the knowledge of economics to a single volume. The story goes on in this vein, as such stories will, until the advisers are required, if they are to survive, to reduce the totality of economic science to a single sentence. This is the origin of the “free lunch” law.

In ecology, as in economics, the law is intended to warn that every gain is won at some cost. In a way, this ecological law embodies the previous three laws. Because the global ecosystem is a connected whole, in which nothing can be gained or lost

and which is not subject to over-all improvement, but from it by human effort must be replaced. Payment of this price cannot be avoided; it can only be delayed. The present environmental crisis is a warning that we have delayed nearly too long.

The preceding pages provide a view of the web of life on the earth. An effort has been made to develop this view from available facts, through logical relations, into a set of comprehensive generalizations. In other words, the effort has been scientific.

Nevertheless, it is difficult to ignore the embarrassing fact that the final generalizations which emerge from all this—the four laws of ecology—are ideas that have been widely held by many people without any scientific analysis or professional authorization. The complex web in which all life is enmeshed, and man's place in it, are clearly—and beautifully—described in the poems of Walt Whitman. A great deal about the interplay of the physical features of the environment and the creatures that inhabit it can be learned from *Moby Dick*. Mark Twain is not only a marvelous source of wisdom about the nature of the environment of the United States from the Mississippi westward, but also a rather incisive critic of the irrelevance of science which loses connection to the realities of life. As the critic Leo Marx reminds us, "Anyone familiar with the work of the classic American writers (I am thinking of men like Cooper, Emerson, Thoreau, Melville, Whitman, and Mark Twain) is likely to have developed an interest in what we recently have learned to call ecology."

Unfortunately, this literary heritage has not been enough to save us from ecological disaster. After all, every American technician, industrialist, agriculturalist, or public official who has condoned or participated in the assault on the environment has read at least some of Cooper, Emerson, Thoreau, Melville, Whitman, and Mark Twain. Many of them are campers, bird-watchers, or avid fishermen, and therefore to some degree personally aware of the natural processes that the science of ecology hopes to elucidate. Nevertheless, most of them were taken unawares by the environmental crisis, failing to understand, apparently, that Thoreau's woods, Mark Twain's rivers, and Melville's oceans are *today* under attack.

The rising miasma of pollution has helped us to achieve this understanding. For, in Leo Marx's⁵ words, "The current environmental crisis has in a sense put a literal, factual, often quantifiable base under this poetic idea [i.e., the need for human harmony with nature]." This is perhaps the major value of the effort to show that the simple generalizations which have already emerged from perceptive human contact with the natural world have a valid base in the facts and principles of a science, ecology. Thus linked to science, these ideas become tools for restoring the damage inflicted on nature by the environmental crisis.

In the woods around Walden Pond or on the reaches of the Mississippi, most of the information needed to understand the natural world can be gained by personal

5. Leo Marx: American literary and cultural critic (b. 1919) and author of *The Machine in the Garden* (1964).

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experience. In the world of nuclear bombs, smog, and foul water, environmental understanding needs help from the scientist.

UNDERSTANDING THE TEXT

1. Summarize Commoner's four laws of ecology in your own words. What are these laws? Are they provable and absolute the way that the laws of physics are?
2. How does Commoner define "cybernetics"? What is the connection between a cybernetic system and an ecosystem?
3. What keeps ecosystems in balance? Is it possible for an ecosystem to become so unbalanced that it stops functioning? How?
4. What does Commoner mean by "eutrophication"? How can it contribute to the collapse of an ecosystem?
5. What determines the amount of stress that a system can absorb? What happens when a system is no longer able to absorb stress?
6. Why does Commoner say that there is no such thing as waste? What happens to the materials that we commonly refer to as waste substances?
7. Is human intervention always detrimental to an ecosystem? Why is it more likely to be detrimental than beneficial?

MAKING CONNECTIONS

1. How would Charles Darwin (p. 314) interpret the rabbit-lynx dynamic that Commoner discusses? Is Commoner ultimately explaining an evolutionary system?
2. Do Commoner's observations about DDT confirm or challenge the assertions of Rachel Carson (p. 328)? Would Carson agree that DDT moves up the food chain?
3. Like William Paley (p. 311), Commoner uses the metaphor of a watch to describe the natural world. In what ways are the two watch metaphors similar? How are they different?

WRITING ABOUT THE TEXT

1. Examine an ecosystem you are familiar with, such as a local park or waterway. Choose five or six elements of this ecosystem and explain, using Commoner's terms, how all of these elements are related to each other.
2. Select one of Commoner's four laws of ecology and try to falsify it (Popper, p. 336). Think of ways that the law might not be universally applicable and, therefore, not really a "law" in the scientific sense.
3. Use Commoner's four laws of ecology to analyze one of the following readings: Rachel Carson's "The Obligation to Endure" (p. 328), Wangari Maathai's "Foresters Without Diplomas" (p. 363), or Vandana Shiva's "Soil, not Oil" (p. 374).