2ND | EDITION

Basics of Environmental Science

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1 Introduction

When you have read this chapter you will have been introduced to:

- a definition of the disciplines that comprise the environmental sciences
- cycles of elements and environmental interactions
- the difference between ecology and environmentalism
- the history of environmental science
- attitudes to the natural world and the way they change over time

1 What is environmental science?

There was a time when, as an educated person, you would have been expected to converse confidently about any intellectual or cultural topic. You would have read the latest novel, been familiar with the work of the better-known poets, have had an opinion about the current state of art, musical composition and both musical and theatrical performance. Should the subject of the conversation have changed, you would have felt equally relaxed discussing philosophical ideas. These might well have included the results of recent scientific research, for until quite recently the word 'philosophy' was used to describe theories derived from the investigation of natural phenomena as well as those we associate with philosophy today. The word 'science' is simply an anglicized version of the Latin *scientia,* which means 'knowledge'. In German, which borrowed much less from Latin, what we call 'science' is known as *Wissenschaft,* literally 'knowledge'. 'Science' did not begin to be used in its restricted modern sense until the middle of the last century.

As scientific discoveries accumulated it became increasingly difficult, and eventually impossible, for any one person to keep fully abreast of developments across the entire field. A point came when there was just too much information for a single brain to hold. Scientists themselves could no longer switch back and forth between disciplines as they used to do. They became specialists and during this century their specialisms have divided repeatedly. As a broadly educated person today, you may still have a general grasp of the basic principles of most of the specialisms, but not of the detail in which the research workers themselves are immersed. This is not your fault and you are not alone. Trapped inside their own specialisms, most research scientists find it difficult to communicate with those engaged in other research areas, even those bordering their own. No doubt you have heard the cliché defining a specialist as someone who knows more and more about less and less. We are in the middle of what journalists call an 'information explosion' and most of that information is being generated by scientists.

Clearly, the situation is unsatisfactory and there is a need to draw the specialisms into groups that will provide overarching views of broad topics. It should be possible, for example, to fit the work of the molecular biologist, extracting, cloning, and sequencing DNA, into some context that would relate it to the work of the taxonomist, and the work of both to that of the biochemist. What these disciplines share is their subject matter. All of them deal with living or once-living organisms. They deal with life and so these, as well as a whole range of related specialisms, have come to be grouped together as the life sciences. Similarly, geophysics, geochemistry, geomorphology, hydrology, mineralogy, pedology, oceanography, climatology, meteorology, and other disciplines are now grouped as the earth sciences, because all of them deal with the physical and chemical nature of the planet Earth.

The third, and possibly broadest, of these groupings comprises the environmental sciences, sometimes known simply as 'environmental science'. It embraces all those disciplines which are concerned with the physical, chemical, and biological surroundings in which organisms live. Obviously, environmental science draws heavily on aspects of the life and earth sciences, but there is some unavoidable overlap in all these groupings. Should palaeontology, for example, the study of past life, be regarded as a life science or, because its material is fossilized and derived from rocks, an earth science? It is both, but not necessarily at the same time. The palaeontologist may date a fossil and determine the conditions under which it was fossilized as an earth scientist, and as a life scientist reconstruct the organism as it appeared when it was alive and classify it. It is the direction of interest that defines the grouping.

Any study of the Earth and the life it supports must deal with process and change. The earth and life sciences also deal with process and change, but environmental science is especially concerned with changes wrought by human activities, and their immediate and long-term implications for the welfare of living organisms, including humans.

At this point, environmental science acquires political overtones and leads to controversy. If it suggests that a particular activity is harmful, then modification of that activity may require national legislation or an international treaty and, almost certainly, there will be an economic price that not everyone will have to pay or pay equally. We may all be environmental winners in the long term, but in the short term there will be financial losers and, not surprisingly, they will complain.

Over the last thirty years or so we have grown anxious about the condition of the natural environment and increasingly determined to minimize avoidable damage to it. In most countries, including the United States and European Union, there is now a legal requirement for those who propose any major development project to calculate its environmental consequences, and the resulting environmental impact assessment is taken into account when deciding whether to permit work to proceed. Certain activities are forbidden on environmental grounds, by granting protection to particular areas, although such protection is rarely absolute. It follows that people engaged in the construction, extractive, manufacturing, power-generating or power-distributing, agricultural, forestry, or distributive industries are increasingly expected to predict and take responsibility for the environmental effects of their activities. They should have at least a general understanding of environmental science and its application. For this reason, many courses in planning and industrial management now include an environmental science component.

This book provides an overview of the environmental sciences. As with all the broad scientific groupings, opinions differ as to which disciplines the term covers, but here the net is cast widely. All the topics it includes are generally accepted as environmental sciences. That said, the approach adopted in *Basics of Environmental Science* is not the only one feasible. In this rapidly developing field there is a variety of ideas about what should be included and emphasized and what constitutes an environmental scientist.

This opening chapter provides a general introduction to environmental science, its history, and its relationship to environmental campaigning. It is here that an important point is made about the overall subject and the content of the book: environmental science and 'environmentalism' are not at all the same thing. Environmental science deals with the way the natural world functions; environmentalism with such modifications of human behaviour as reformers think appropriate in the light of scientific findings. Environmentalists, therefore, are concerned with more than just science. As its title implies, *Basics of Environmental Science* is concerned mainly with the science.

The introduction is followed by four chapters, each of which deals with an aspect of the fundamental earth and life sciences on which environmental science is based, in each case emphasizing the importance of process and change and, where appropriate, relating the scientific description of what happens to its environmental implications and the possible consequences of perturbations to the system. The fifth and final chapter deals with environmental management, covering such matters as wildlife conservation, pest control, and the control of pollution.

You do not have to be a scientist to understand *Basics of Environmental Science*. Its language is simple, non-technical, and non-mathematical, but there are suggestions for further reading to guide those who wish to learn more. Nor do you have to read the book in order, from cover to cover. Dip into it in search of the information that interests you and you will find that each short block is quite self-contained.

It is the grouping of a range of disciplines into a general topic, such as environmental science, which makes it possible to provide a broad, non-technical introduction. The grouping is natural, in that the subjects it encompasses can be related to one another and clearly belong together, but it does not resolve the difficulty of scientific specialization. Indeed, it cannot, for the great volume of specialized information that made the grouping desirable still exists. Except in a rather vague sense, you cannot become an 'environmental scientist', any more than you could become a 'life scientist' or an 'earth scientist'. Such imprecise labels have very little meaning. Were you to pursue a career in the environmental sciences you might become an ecologist, perhaps, or a geomorphologist, or a palaeoclimatologist. As a specialist you would contribute to our understanding of the environment, but by adding detailed information derived from your highly specialized research.

Environmental science exists most obviously as a body of knowledge in its own right when a team of specialists assembles to address a particular issue. The comprehensive study of an important estuary, for example, involves mapping the solid geology of the underlying rock, identifying the overlying sediment, measuring the flow and movement of water and the sediment it carries, tracing coastal currents and tidal flows, analysing the chemical composition of the water and monitoring changes in its distribution and temperature at different times and in different parts of the estuary, sampling and recording the species living in and adjacent to the estuary and measuring their productivity.[1] The task engages scientists from a wide range of disciplines, but their collaboration and final product identifies them all as 'environmental scientists', since their study supplies the factual basis against which future decisions can be made regarding the environmental desirability of industrial or other activities in or beside the estuary. Each is a specialist; together they are environmental scientists, and the bigger the scale of the issue they address the more disciplines that are likely to be involved. Studies of global climate change currently engage the attention of climatologists, palaeoclimatologists, glaciologists, atmospheric chemists, oceanographers, botanists, marine biologists, computer scientists, and many others, working in institutions all over the world.

You cannot hope to master the concepts and techniques of all these disciplines. No one could, and to that extent the old definition of an 'educated person' has had to be revised. Allowing that in the modern world no one ignorant of scientific concepts can lay serious claim to be well educated, today we might take it to mean someone possessing a general understanding of the scientific concepts from which the opinions they express are logically derived. In environmental matters these are the concepts underlying the environmental sciences. *Basics of Environmental Science* will introduce you to those concepts. If, then, you decide to become an environmental scientist the book may help you choose what kind of environmental scientist to be.

2 Environmental interactions, cycles, and systems

Inquisitive children sometimes ask whether the air they breathe was once breathed by a dinosaur. It may have been. The oxygen that provides the energy to power your body has been used many times by many different organisms, and the carbon, hydrogen, and other elements from which your body is made have passed through many other bodies during the almost four billion years that life has existed on our planet. All the materials found at the surface of the Earth, from the deepest ocean trenches to the top of the atmosphere, are engaged in cycles that move them from place to place. Even the solid rock beneath your feet moves, as mountains erode, sedimentary rocks are subducted into the Earth's mantle, and volcanic activity releases new igneous rock. There is nothing new or original in the idea of recycling!

The cycles proceed at widely differing rates and rates that vary from one part of the cycle to another. Cycling rates are usually measured as the time a molecule or particle remains in a particular part of the cycle. This is called its 'residence time' or 'removal time'. On average, a dust or smoke particle in the lower atmosphere (the troposphere) remains airborne for a matter of a few weeks at most before rain washes it to the surface, and a water molecule remains in the air for around 9 or 10 days. Material reaching the upper atmosphere (the stratosphere) resides there for much longer, sometimes for several years, and water that drains from the surface into ground water may remain there for up to 400 years, depending on the location.

Water that sinks to the bottom of the deep oceans eventually returns to the surface, but this takes very much longer than the removal of water molecules from the air. In the Pacific Ocean, for example, it takes 1000 to 1600 years for deep water to return to the surface and in the Atlantic and Indian Oceans it takes around 500 to 800 years (MARSHALL, 1979). This is relevant to concerns about the consequences of disposing industrial and low-level radioactive waste by sealing it in containers and dumping them in the deep oceans.

Those monitoring the movement of materials through the environment often make use of labelling, different labels being appropriate for different circumstances. In water, chemically inert dyes are often used. Certain chemicals will bond to particular substances. When samples are recovered, analysis reveals the presence or absence of the chemical label. Radioisotopes are also used. These consist of atoms chemically identical to all other atoms of the same element, but with a different mass, because of a difference in the number of neutrons in the atomic nucleus. Neutrons carry no charge and so take no part in chemical reactions, the chemical characteristics of an element being determined by the number of protons, with a positive charge, in its atomic nucleus.

You can work out the atmospheric residence time of solid particles by releasing particles labelled chemically or with radioisotopes and counting the time it takes for them to be washed back to the ground, although the resulting values are very approximate. Factory smoke belching forth on a rainy day may reach the ground within an hour or even less; the exhaust gases from an aircraft flying at high altitude will take much longer, because they are further from the ground to start with and in much drier air. It is worth remarking, however, that most of the gases and particles which pollute the air and can be harmful to health have very short atmospheric residence times. Sulphur dioxide, for example, which is corrosive and contributes to acid rain, is unlikely to remain in the air for longer than one month and may be washed to the surface within one minute of being released. The atmospheric residence time for water molecules is calculated from the rate at which surface water evaporates and returns as precipitation.

The deep oceans are much less accessible than the atmosphere, but water carries a natural label in the form of carbon-14(^{14}C). This forms in the atmosphere through the bombardment of nitrogen

(^{14}N) by cosmic radiation, but it is unstable and decays to the commoner ^{12}C at a steady rate. While water is exposed to the air, both ^{12}C and ^{14}C dissolve into it, but once isolated from the air the decay of ^{14}C means that the ratio of the two changes, ^{12}C increasing at the expense of ^{14}C. It is assumed that ^{14}C forms in the air at a constant rate, so the ratio of ^{12}C to ^{14}C is always the same and certain assumptions are made about the rate at which atmospheric carbon dioxide dissolves into sea water and the rate at which water rising from the depths mixes with surface water. Whether or not the initial assumptions are true, the older water is the less ^{14}C it will contain, and if the assumptions are true the age of the water can be calculated from its ^{14}C content in much the same way as organic materials are ^{14}C-dated.

Carbon, oxygen, and sulphur are among the elements living organisms use and they are being cycled constantly through air, water, and living cells. The other elements required as nutrients are also engaged in similar biogeochemical cycles. Taken together, all these cycles can be regarded as components of a very complex system functioning on a global scale. Used in this sense, the concept of a 'system' is derived from information theory and describes a set of components which interact to form a coherent, and often self-regulating, whole. Your body can be considered as a system in which each organ performs a particular function and the operation of all the organs is coordinated so that you exist as an individual who is more than the sum of the organs from which your body is made.

Biochemical cycles

The surface of the Earth can be considered as four distinct regions and because the planet is spherical each of them is also a sphere. The rocks forming the solid surface comprise the lithosphere, the oceans, lakes, rivers, and icecaps form the hydrosphere, the air constitutes the atmosphere, and the biosphere contains the entire community of living organisms.

Materials move cyclically among these spheres. They originate in the rocks (lithosphere) and are released by weathering or by volcanism. They enter water (hydrosphere) from where those serving as nutrients are taken up by plants and from there enter animals and other organisms (biosphere). From living organisms they may enter the air (atmosphere) or water (hydrosphere). Eventually they enter the oceans (hydrosphere), where they are taken up by marine organisms (biosphere). These return them to the air (atmosphere), from where they are washed to the ground by rain, thus returning to the land.

The idea that biogeochemical cycles are components of an overall system raises an obvious question: what drives this system? It used to be thought that the global system is purely mechanical, driven by physical forces, and, indeed, this is the way it can seem. Volcanoes, from which atmospheric gases and igneous rocks erupt, are purely physical phenomena. The movement of crustal plates, weathering of rocks, condensation of water vapour in cooling air to form clouds leading to precipitation—all these can be explained in purely physical terms and they carry with them the substances needed to sustain life. Organisms simply grab what they need as it passes, modifying their requirements and strategies for satisfying them as best they can when conditions change.

Yet this picture is not entirely satisfactory. Consider, for example, the way limestone and chalk rocks form. Carbon dioxide dissolves into raindrops, so rain is very weakly acid. As the rain water washes across rocks it reacts with calcium and silicon in them to form silicic acid and calcium bicarbonate, as separate calcium and bicarbonate ions. These are carried to the sea, where they react to form calcium carbonate, which is insoluble and slowly settles to the sea bed as a sediment that, in time, may be compressed until it becomes the carbonate rock we call limestone. It is an entirely inanimate process. Or is it? If you examine limestone closely you will see it contains vast numbers of shells, many of them minute and, of course, often crushed and deformed. These are of biological origin. Marine organisms 'capture' dissolved calcium and bicarbonate to 'manufacture' shells of calcium carbonate. When they die the soft parts of their bodies decompose, but their insoluble shells sink to the sea bed. This appears to be the principal mechanism in the formation of carbonate rocks and it has occurred on a truly vast scale, for limestones and chalks are among the commonest of all sedimentary rocks. The famous White Cliffs of Dover are made from the shells of once-living marine organisms, now crushed, most of them beyond individual recognition.

Here, then, is one major cycle in which the biological phase is of such importance that we may well conclude that the cycle is biologically driven, and its role extends further than the production of rock. The conversion of soluble bicarbonate into insoluble calcium carbonate removes carbon, as carbon dioxide, from the atmosphere and isolates it. Eventually crustal movements may return the rock to the surface, from where weathering returns it to the sea, but its carbon is in a chemically stable form. Other sedimentary rock on the ocean floor is subducted into the mantle. From there its carbon is returned to the air, being released volcanically, but the cycle must be measured in many millions of years. For all practical purposes, most of the carbon is stored fairly permanently. As the newspapers constantly remind us, carbon dioxide is a 'greenhouse gas', one of a number of gases present in the atmosphere that are transparent to incoming, short-wave solar radiation, but partially opaque to long-wave radiation emitted from the Earth's surface when the Sun has warmed it. These gases trap outgoing heat and so maintain a temperature at the surface markedly higher than it would be were they absent. Since the Earth formed, some 4.6 billion years ago, the Sun has grown hotter by an estimated 25 to 30 per cent, and the removal of carbon dioxide from the air, to a significant extent as a result of biological activity, has helped prevent surface temperatures rising to intolerable levels.

Gaia

A hypothesis, proposed principally by James Lovelock, that all the Earth's biogeochemical cycles are biologically driven and that on any planet which supports life conditions favourable to life are maintained biologically. Lovelock came to this conclusion as a result of his participation in the preparations for the explorations of the Moon and Mars. One object of the Mars programme was to seek signs of life on the planet. Martian organisms, should they exist, might well be so different from organisms on Earth as to make them difficult to recognize as being alive at all. Lovelock reasoned that the one trait all living organisms share is their modification of the environment. This occurs when they take materials from the environment to provide them with energy and structural materials, and discharge their wastes into the environment. He argued that it should be possible to detect the presence of life by an environment, especially an atmosphere, that was far from chemical equilibrium. Earth has such an atmosphere, with anomalously