2

Science on environmental problems

Peter B. Sloep and Maria C. E. van Dam-Mieras

2.1 Introduction

In the previous chapter environmental problems were discussed in terms of their interconnection with other problems that our modern world faces. Here we look at environmental problems from the vantage point of the natural sciences. In particular, we shall attempt to assess how the natural sciences may further our understanding and control of environmental problems.

Two rather extreme stances are sometimes taken on this matter: that science is totally irrelevant or that it is sufficient on its own. The science sceptic claims that, ultimately, political compromise is all there is to environmental problem solving (see Glasbergen, 1993, who briefly discusses this position), whereas the science diehard believes that science is all you need. We believe the sceptic's position to be wrong, even though politicians may sometimes seem to act according to it. To us, science has genuinely useful insights to offer that can only be ignored at everyone's peril. But we do not side with the science diehards either. That position is an almost arrogant overestimation of the capability of science.

Both positions err in that they entertain much too simple a notion of our environmental predicament. First and foremost, environmental problems are social constructions. Notwithstanding this, any environmental problem also has an objective side, something which cannot be altered at will, through social consensus or otherwise. This leads us to believe that scientific knowledge is necessary but not sufficient to solve environmental problems. This is the perspective that the present chapter has to offer.

The chapter is divided into five major parts. The next section (2.2) provides relevant background knowledge as it attempts to outline a scientific, that is, ecology-based, view of our world. It does so by regarding the biosphere – the collective ecosystem of our world – as a machine. In particular, the importance of energy transport and of material cycles needed to keep the machine running will be discussed. An environmental problem, one might say, is anything that obstructs the machine's proper functioning. In our view, however, this machine metaphor is naive, perhaps even to the point of being misleading. Why this is so and what would be a better definition of an environmental problem is the subject of the next section (2.3).

Having discussed in a general way the nature of the environment and of environmental problems, section 2.4 discusses actual environmental problems. A concise overview is given of the historical changes in our society that led to our present-day problems. Emphasis will be put on the impacts of the Industrial and Green Revolutions in the developed countries of the North as these might fulfil an exemplary role. The next section (2.5) is devoted to the problem of solving and preventing environmental problems. It discusses a scheme for bringing scientific knowledge to bear upon environmental problem solving. This results in a multidisciplinary view of environmental problem solving and hence environmental decision making. The final section (2.6) draws our main conclusions.

2.2 The environment in the eyes of a natural scientist

It almost amounts to a truism to say that the environment is of vital importance to living organisms. And indeed, organisms of all species, including *Homo sapiens*, live in continuous interaction with their environment. They import from it the energy and raw materials needed for growth, development and reproduction. Because of the intimacy of the interaction with the environment, the environment also constitutes a threat to organisms. This is true for the non-living parts of the environment (the so-called abiotic factors) such as extreme humidities or temperatures, fluctuations of humidity or temperature, acidity, lack of oxygen, etc. It also holds for the living part (the biotic factors), i.e. other organisms, which may act as infectants, parasites, predators or competitors. After all, these organisms use their environment for their own survival, thus affecting the survival of others. Organisms, of course, have evolved strategies to ward off these threats, and maintain themselves in the 'struggle for life'. Most of the time these strategies work well, but there are limits to their efficacy. Certain changes in the environment, whether biotic or abiotic, pose insurmountable problems to organisms. Changes may be so novel, emerge so suddenly or fluctuate so wildly that they exceed the (genetically determined) physiological limits of adaptation of organisms, ultimately leading to their demise. Furthermore, if the changes occur sufficiently rapidly, the process of coping through evolution, that is, through changes in the genetic make-up of organisms, is simply too slow. In such cases entire species may end up becoming extinct.

Natural disasters are good examples of such drastic environmental changes. Extensive floods or fires and volcanic eruptions are eventualities that hardly any organism can prepare itself for. But such accidents, one might say, are among the natural risks of life. Recently, however, a new class of threats has emerged, for which organisms cannot prepare themselves either. We are referring here to *environmental problems*.

Before discussing environmental problems, however, we need to know a little more about the exact ways in which organisms cope with their 'normal' environment. As environmental problems are our ultimate interest, we can afford to limit our discussion to those modes of interaction that are particularly relevant to our topic proper.

Ecosystems and food webs

Tracing all the nutritional relationships in some ecosystem (see Box 1) would effectively amount to outlining a *food web*. Food webs are not haphazardly put together by nature, but display an intricate organisation. Although no ecosystem is identical in its details to another, some general rules exist that apply to most of them. Barring some exotic ecosystems (such as those near thermal vents deep in the ocean or those in secluded caves) all food webs have plants as their most important primary producers. Through a process called *photosynthesis*, plants capture solar energy and store it as chemical energy. Plants are eaten by animals and other organisms, collectively called herbivores. Being eaten means that not only matter is transferred 'one level up' but also the energy stored in the food. The herbivores, in turn, are eaten by animals of a higher level called predators, who in their turn may be eaten by yet other predators. The predators again transfer matter and energy. It thus appears to be the 'function' of food

1

Food webs

Organisms do not occur in nature in haphazard collections; they are to some extent organised. Although dichotomising easily leads to oversimplification, we will assume for the sake of our argument that there are two fundamentally different, though complementary ways of looking at these organised collections of organisms.

The first approach, called *ecosystem* ecology, focuses on functional groups of organisms (herbivores, predators, prey, etc.). Organisms within such groups belong to different species but are grouped together because they perform the same functional role in the ecosystem. (The concept of an ecosystem is hard to define as it is always used in a rather loose way; roughly, an ecosytem encompasses the organisms that live in an area and the abiotic, physical aspects of that area affecting the organisms.)

The ecosystem approach investigates the transfer of energy and matter between the functional groups within the ecosystem. The second approach, called *community* ecology, focuses on populations of organisms. A population is a group of organisms that inhabit a particular area and belong to a particular species. The community approach mainly investigates competitive relations between and within populations.

The present chapter takes the ecosystem approach because it focuses on energy relations and nutrient cycles. Had the focus of interest been nature conservation and biodiversity issues, the community would have been chosen as this lends itself better to a discussion of these issues. In the ecosystem approach, food webs play a crucial role. One of the earliest examples of a quantitative analysis of food webs was that by the late American ecologist Raymond Lindeman. Figure 2.1 derives from his classic paper on the subject and aptly illustrates the concept of a food web (Lindeman, 1942).

webs in an ecosystem to transfer energy and matter, and the various organisms in the ecosystem play their different roles in sustaining this transfer. We shall now look a little closer at the process of transfer.

The transfer of energy and matter

Apart from a few exceptional cases, the sole energy source for plants is solar radiation (see Figure 2.1; the exceptions include parasitic or saprophytic plants, plants that live at the expense of other living or dead plants). Plants store this energy in carbon compounds. The carbon needed for this is derived from carbon dioxide, which is abundantly available in the atmosphere. During photosynthesis, solar energy is converted to chemical energy and stored in the bonding energy (roughly the energy needed to keep the molecule together) of molecules of sugar, a carbon compound. For similar reasons, petrol is also an energy source. These sugar molecules can be regarded as the plant's reservoir of both raw materials and energy. The sugar molecules are

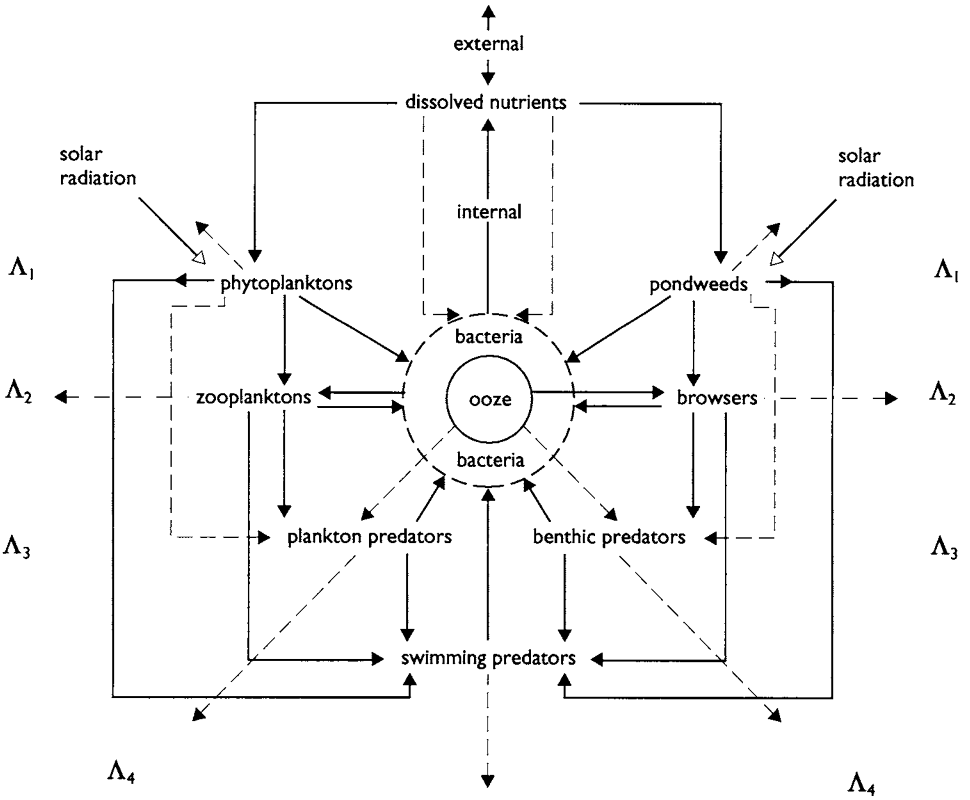


Fig. 2.1 A classic example of a food web.The phytoplanktons and pondweeds are the primary producers, the zooplanktons and browsers, the herbivores and the organisms called plankton, benthic,and swimming predators the predators.The role of the bacteria is somewhat complicated and therefore left out of consideration. Source: after Lindeman (1942).

transported to all of the plant's cells and converted to other compounds by the various reactions in the plant's metabolism. These compounds make up the various components of plant cells, which consist mainly of the elements carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur. In addition to these, there are small amounts of other elements. The role of these so-called trace elements is to catalyse ('speed up') cellular metabolism; they are taken up from the soil by the roots of the plant. Nitrogen, phosphorus and sulphur-containing compounds are also absorbed from the soil.

In short, plants absorb a variety of nutrients from their environment and trap the energy of sunlight in the form of chemical energy. They need both nutrients and energy for their growth, maintenance and reproduction.

Because plants are eaten, they serve as a source of energy and nutrients for other organisms, particularly the herbivores. Plants are a source of nutrients (food) because all organisms, in spite of their tremendous diversity, are largely composed of the same four main groups of molecules (carbohydrates, lipids, proteins and nucleic acids). Hence, herbivores are not confronted with completely foreign substances. Also, the major metabolic pathways in organisms, i.e. the chains of chemical reactions which various compounds in the cells of organisms undergo, are remarkably similar. Therefore, to the extent that chemical conversions are required, they are well within the capacities of the herbivores. Indeed, with the exception of plants, which need the sun as their energy source, all organisms can potentially use each other as sources of energy and raw materials. It is because of these similarities in substances and in reaction chains that herbivores can live off plants, and predators can make a living out of preying on herbivores and other predators.

Both herbivores and predators absorb their food in basically the same way. During its passage through their alimentary tract (stomach(s), intestines), the nutritional source is degraded into smaller molecules, which are taken up by cells of the alimentary tract. In turn, these molecules may be further transported via the blood and imported into the cells of other organs of the body. Within these cells, the molecules are degraded further until they are fit for the biosynthesis of cellular compounds. At the same time, some of the compounds obtained are used to generate energy in a form that can be used by cells (adenosine triphosphate, ATP for short, is the common energy currency). Some predators – the so-called top predators – are not themselves preyed upon. When they die they are eaten by micro-organisms, collectively called decomposers, as is all organic material that is not otherwise consumed. The micro-organisms break down – degrade – complex organic molecules into the simple ones that they can use for their own metabolism. Once again, the similarity principle reigns.

The above description of the biosphere-machine is very sketchy. We have left out all sorts of complexities such as the role of scavengers, the existence of non-photosynthetic primary producers and photosynthetic micro-organisms, the role of certain fungi (higher organisms that are able to degrade complex molecules), etc. The discussion, however, has highlighted two important principles that govern the biosphere.

The first principle states that there is a flow of energy within ecosystems from photosynthetic plants (or, generally speaking, autotrophs) to non-photosynthetic organisms (generally speaking, heterotrophs). The energy flow is essentially *linear* in that it is a one-way flow, from autotrophs to heterotrophs. Furthermore – and this is a fundamental law of physics – only part of the energy remains available in usable form of transformation steps in an ecosystem or, in other words, the number of levels in the food web is therefore limited. The situation may be likened to travelling through the European Community, exchanging money for the local currency at every border. Not only does the initial sum diminish because money is spent on the way on food, lodging, etc., but at every border a fraction of the remaining sum is lost in the exchange process. Indeed, given enough crossings, any sum will dwindle to nothing because of the exchange fees alone. In much the same way, energy is not only used for 'living', but a fraction of the energy is also lost at any transfer step, because it is turned into non-usable heat. This degradation of the quality of energy, as it is sometimes called, is as much a law of nature as is the conservation of its total amount.

The second principle says that there is a flow of matter in all ecosystems. Unlike the flow of energy, this flow is *cyclic*. Plants are dependent upon heterotrophic organisms to regenerate carbon dioxide (which the latter 'exhale' when 'breathing') and minerals. Plants need these in order to carry out photosynthesis and build their own cellular constituents. The same is true for many other elements, such as nitrogen and sulphur. The cyclic flow of carbon and other elements within the biosphere is well documented. The cycles are usually referred to as *geochemical cycles*. As the organisms in the ecosystem carry out the transport by eating and being eaten, it is photosynthesis and, in the final analysis, solar energy that provides the power input driving the mineral cycles.

Ecosystem functioning and malfunctioning

The general overview of the natural or, more precisely, ecological order just given may suggest that we are dealing with a system that is able to sustain itself indefinitely. The continued energy input from the sun – needed to compensate for the losses – and the

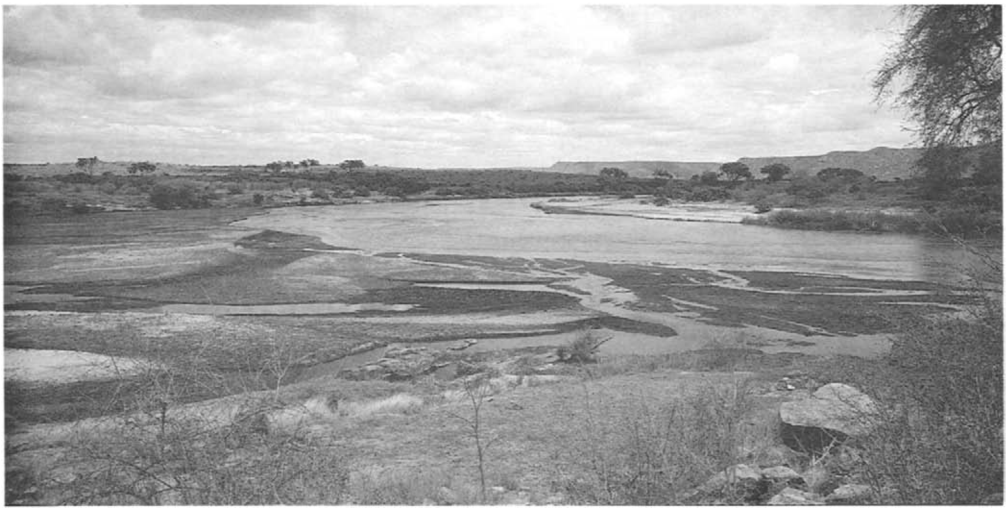


Plate 2.1 The natural order: an ecosystem without human interference, Isavo, Kenya. Photo: Fred Hoogervorst/Lineair

continued energy input from the sun – needed to compensate for the losses – and the cyclical flow of elements would seem to suffice to keep the machinery running for ever. But the truth of this conjecture depends on what exactly we mean by it. If we refer to the ability of ecosystems – and even of the biosphere as a whole – to persist over a prolonged period of time, we are basically correct. Life on Earth is already about 3.5 billion (thousand million) years old. If, however, we interpret it as an unaltered persistence, we miss an important point.

Current life forms only remotely resemble the earliest ones. Organisms have evolved over time and continue to do so (see Box 2). They evolve in response to changes in their environment. The metabolic capabilities of organisms, for example, change continuously; their efficiency in collecting food and ability to cope with parasites and predators change too, as do their defences against unfavourable abiotic changes in environmental conditions. As an ultimate consequence of all these changes, some species become extinct and others emerge. Thus, over evolutionary time, we witness all kinds of shifts in the biological components which take part in the geocycles. Notwithstanding this dynamic feature, the overall picture of (re)cycling materials and linearly transferring energy has remained unaltered. In the absence of large-scale infringements that are forced upon this slowly evolving system, we could indeed safely claim that it will continue to exist for aeons to come.

Unfortunately, the present day indeed witnesses infringements large enough to upset the ecosystems of the world. The development of modern technology – in a broad sense – has, on the time-scale that evolution operates on, taken place in a very short time indeed (decades or centuries rather than thousands or millions of years). The natural world, largely reliant upon the evolutionary mechanisms for its adaptation to changing environmental circumstances, requires significant periods of time to adapt. To what extent the present interferences with the biosphere, caused by human activities, pose threats to the ability of the biosphere to sustain itself remains an open question. There is no doubt, though, that notable changes in the biosphere's functioning are to be expected. Indeed, many argue that such changes have taken place already. They point to the growing percentage of solar energy that flows into agricultural ecosystems rather than natural ones (see Vitousek, 1986) or to the increased concentration of greenhouse gases such as carbon dioxide and methane. Sooner or later, these changes will significantly alter current patterns of the transfer of energy and the recycling of materials. When that occurs, grave problems are to be expected for the entire biosphere, affecting us human beings too. For example, climate change, one of the best known consequences of the increased concentrations of greenhouse gases, is likely to occur. For its part climate change will have all kinds of unwanted consequences, droughts here, excessive rainfall elsewhere, flooding, etc.

The upshot is that we should examine closely the infringements that we humans inflict upon the biosphere, investigate their disruptive effects, and determine how best to repair them or avoid them in the future. After all, although we can afford mentally to step outside the biosphere, physically we are animals among the animals, organisms among the organisms.

The sections to come will be devoted to looking at the nature of environmental problems. In them we will take the perspective of a natural scientist. Before embarking upon this task, however, there is an important preliminary concern to be dealt with. The

2

Evolution

Life on Earth is the result of a long and slow process of non-directional change. Starting with very simple organisms, a great diversity of organisms, both complex and simple, has arisen in the course of about 3.5 billion years. However, it is not only the bewildering diversity of organisms which requires explanation, but also their remarkable adaptation to the environment. The process responsible for the adaptations is called *natural selection*. It only occurs if the following three conditions have been fulfilled.

First, organisms of the same species differ in their characteristics, physical, behavioural or otherwise. This is called the *principle of variation*. Secondly, this variation is heritable, i.e. parents transmit to their offspring the characteristics that set them apart from their conspecifics (*principle of heredity*). Thirdly, parents leave different numbers of offspring, the numbers reflecting their ability to cope with the threats – both biotic and abiotic – the environment poses: the better they are able to cope, the longer they live and the more offspring they will produce. This is the *principle of natural selection*. Evolution thus takes place because there is heritable variation in coping abilities that natural selection works on. It results in organisms that are ever better adapted to their environment.

Evolution, however, is slow because its measure is the generation time of a species. Bacteria are thus able to react more quickly to a changing environment than, say, humans, because bacteria might produce a new generation within 25 minutes, whereas it takes humans about 25 years. There is thus an upper limit to the speed with which species can adapt to a changing environment by evolutionary means.

But organisms adapt to their environment not only through natural selection but also by physiological means. They may grow a thicker fur in winter, adjust their skin colour, hibernate, shed leaves, etc. All these adaptations take place within the lifespan of an organism and are hence referred to as changes at an ecological time-scale. This offers organisms an alternative way of coping with environmental changes. However, here too possibilities are limited.

The very abilities to grow a thicker fur, adjust skin colour, hibernate, shed leaves, etc. are themselves products of a process of natural selection: they are themselves evolutionary adaptations. Although ecological (physiological) adaptations are thus much faster than evolutionary ones, they are also limited in their possibilities, limits which are set by evolution.

But why not be highly flexible then, one may ask.

After all, this seems to offer the best chance to cope with a quickly or erratically changing environment. Research, however, has revealed that flexibility comes with a high price. Being flexible in some respect always means being rigid in some other: one person cannot win both the marathon and the 100 metres in the Olympics. One way or the other, a too rapidly changing environment always endangers species survival.

notion of an infringement as used in the previous section is very much a scientific one: a disruption of natural ecosystems. As such it seems unproblematic. The question arises, however, of how it is related to the cognate notion of an environmental problem. After all, as we saw in Chapter 1, environmental problems have similar features. Clearly, not all infringements automatically qualify as environmental problems; but which ones do? Might one say, for instance, that once infringements have caught the public eye they qualify as environmental problems? Or is there more to it? As we shall see, it is indeed necessary to probe for the exact connection between the notions of an infringement and an environmental problem, as there are important consequences for the ways in which we should solve and avoid environmental problems. That is what the next section will do.

2.3 What constitutes an environmental problem?

The physical dimension

So, what then is an environmental problem exactly? We will tackle this question in a stepwise fashion: suggest a definition, discuss its limitations, and refine it accordingly, until a satisfactory answer has been obtained (see also Sloep, 1994).

First, any definition should restrict environmental problems to changes in the physical environment and rule out changes in our social environment. This follows from our discussion of infringements above: they are infringements of *natural* systems. But the restriction is useful on independent grounds too. Not many, for instance, would argue that the hindrance caused by, say, drug dealing in some neighbourhood should count as an environmental problem; nor would many insist that the misery of having to live under a totalitarian regime is to be considered an environmental problem. Yet both are human interferences with our environment. The point that disqualifies them as environmental problems is that they are changes *solely* of our social environment. If, on the other hand, we look at something like the depletion of the stratospheric ozone layer (the so-called hole in the ozone layer) – commonly seen as a genuine environmental problem – we are dealing with a change in the physical environment. (Later on we will discuss the ozone case in some depth.) Admittedly, this has consequences for our social environment. A case in point would be the dramatically altered attitude of Australians and New Zealanders towards sunbathing (see Figure 2.2).

It should be noted that it is the change in the physical environment that has prompted these responses. It is thus appropriate to describe ozone depletion as an environmental problem and the change in people's attitudes that it prompts as one of its consequences. Keeping these elements apart is crucial, since they have different roles to play, as we shall see shortly. It can be provisionally concluded that:

- an environmental problem is a change of state in the physical environment.

The social dimension

But this characterisation is not sufficiently specific. Not all changes in the physical environment are environmental problems. Consider natural disasters. A case in point would be the damage believed to have been done to the ozone layer by the ashes shot into the air in the June 1991 eruption of Mount Pinatubo in the Philippines (see Kiernan, 1993, and Pitari *et al.*, 1991).

Clearly, this is an infringement of the physical environment, but should it count as an environmental problem? We do not think so. Natural disasters, and other changes

Fig. 2.2 The same advertisement for a suntan lotion in an Australian and a European newspaper. Source: *New Scientist*, 16 May 1992.

not caused by humans, should be disallowed, for including them would cloud the issue of responsibilities and liabilities. An industrial plant using large quantities of ozone-destroying chlorofluorocarbons (CFCs) can be held accountable for damaging the ozone layer. However, Mount Pinatubo cannot possibly be held responsible for obstructing stratospheric ozone production, nor can the inhabitants of the Philippines, for that matter. The crucial difference is that in the former case voluntary human action is to blame, whereas in the latter case it is Nature's exigencies. Since the possibility of legal action is an important element in developing policies for solving environmental problems, a distinction needs to be drawn between human-induced problems and natural disasters.

Of course, one could decide to call both kinds of physical changes environmental problems since, obviously, both concern problems in our environment. But since we wish to retain the possibility of discerning between environmental problems that result from deliberate human intervention and those that do not, this would necessitate the introduction of two new categories: human-made and natural environmental problems. Although this certainly could be done, we have chosen not to, partly because we feel that it is common usage to employ the more restrictive notion.

In passing, it is worth noting that this classification does not automatically relegate all catastrophes to the category of natural disasters. Floods would be a case in point. Often, floods that at first sight appear to be natural disasters turn out to be environmental disasters or problems. Closer inspection reveals them to be ultimately brought about by human actions. Extensive deforestation, for instance, is known to be responsible for many floodings as the water-retaining capabilities of forest soils greatly exceed that of the denuded soils. If such is the case, the apparent natural disaster actually is an environmental problem. These considerations lead us to make the following change to the above definition:

○ An environmental problem is any change of state of the physical environment which is brought about by human interference with the physical environment.

The normative dimension

A crucial element is still lacking, however. A moment's reflection shows that environmental problems essentially carry what may be called a *conventional element*. Let us be more specific. Not all human-made physical changes in the environment should be dubbed environmental problems; only those should be allowed whose consequences are somehow deemed unacceptable. To put some flesh on this rather abstract statement, consider the case of the depletion of the stratospheric ozone layer, mentioned briefly earlier. It is not so much the diminishing of the amount of stratospheric ozone itself that bothers us, but rather its consequences: the increased UV-B radiation which causes a higher incidence of skin cancer, a faster degradation of plastics or altered migratory behaviour or even death of plankton, lowering primary production of coastal shelves and open oceans (plankton constitutes the primary production). And these consequences are unacceptable for various reasons. The increase in skin cancer is unacceptable because it will cause unnecessary suffering and more costly treatments; the shorter lifespan of plastics is unacceptable because it is uneconomical; the diminished primary production is unacceptable because it messes up food webs and reduces fish stocks, which has grave social and economic consequences. Thus, human conventions – agreed upon norms – are crucial in calling some issues environmental problems.

True as this may sound, it is only so up to a point. Closer inspection of the ozone example reveals that matters are a little more complex. Asked to lower immediately the release of ozone-damaging CFCs, the US and Europe reacted in markedly different ways. While in the US non-essential CFCs were banned relatively quickly, the then European Community was slow to act and only recommended a regulation of the production capacities of some CFCs. Although at present no significant differences exist, the interesting point for our discussion is that the US and the EC reacted differently in the face of the same scientific information. The grounds for their different attitudes may be located at two different levels. The first is the level of ethics, the second that of sociology.

First, the norms of what constitute acceptable consequences or effects of an environmental infringement may differ, and this may result in different policies. It is entirely imaginable that the EC and the US have different norms for what constitutes an acceptable increase in the incidence of skin cancer, an acceptable reduction of the economic life of plastics or an acceptable decrease in marine primary production. And even though these are rather technical norms and do not themselves constitute ethical principles, ultimately they are grounded in such principles. This is clearest in the case of the increased incidence of skin cancer. That some people are allowed to have a more pleasant life (because they can afford aerosol cans, fridges, and what have you) at the expense of the suffering or even death of others runs counter to very basic normative, indeed moral principles. And similar cases can be made for social or economic damage, particularly for the peoples of the developing world, where economic damage often is a matter of life and death. So there is no doubt that ethics matter. But there is more, and this relates to the second level mentioned.

Apparently, if differences in (technical) norms exist, different policies could well follow. But this is not a foregone conclusion. More significantly, perhaps, even if the norms are identical, different policies could still arise. The reason for this is that neither ethical principles nor technical norms can be translated into policies in a straightforward manner. The sociopolitical arena decides what shape this translation takes. Conflicts of interest usually abound, compelling one to set priorities between norms. Thus short-term economic prosperity can come to eclipse ‘environmental concerns’, which was probably the real reason behind the EC’s hesitation in the case of the CFC ban. Also, social processes have their own dynamics, leading, for instance, to privileges for the powerful. This is probably the reason why environmental issues in the formerly communist, eastern European countries never made it to the political agenda: the ideology of the power elite prevented this from occurring. In later chapters, starting with the next, this sociopolitical dimension will receive ample attention. We will therefore not go into it any further here. Let us conclude by saying that, alongside ethical considerations, the sociopolitical arena needs to be taken into account when contemplating a definition of environmental problems.

Summarising the discussion, we arrive at the following definition:

○ An environmental problem is any change of state in the physical environment which is brought about by human interference with the physical environment, and has effects which society deems unacceptable in the light of its shared norms.

This definition shows that all environmental problems result from actions that, to some extent, alter the biosphere’s functioning. After all, that is what a change of state in the physical environment boils down to. It also points out that not all such infringements automatically qualify as environmental problems. The ones which do are those whose effects society considers unacceptable. Although in the paragraphs to come we will go into the causes of environmental problems without explicitly mentioning the latter proviso any further, this does not detract from its urgency. Chapters to come, indeed, will pay ample attention to the non-scientific dimensions of environmental problems. Two more observations regarding the definition are in order.

First, it is important to note that incorporating a reference to (shared) norms in the definition of an environmental problem allows us to escape from the commonly made charge of anthropocentrism. This charge holds that our concerns for the environment are ultimately grounded in concerns about our own well-being and that this is much too myopic a point of view. Our definition does not take sides in this debate and we consider this a virtue. It says that ethical norms should feature, but leaves open the question of what norms specifically. Whether one takes an anthropocentric stance or an ecocentric one depends on the system of norms one entertains. If the norms are anthropocentric and framed in terms of, for instance, human health and well-being, so will the notion of an environmental problem. If, however, the norms refer to the well-being of animals, ecosystems or the entire biosphere, anthropocentrism is avoided and replaced by some form of ecocentrism.

Secondly, and for the rest of our discussion most importantly, the definition is an essentially holistic one, one that points out that environmental problems arise out of the interplay between actions belonging to the domain of the natural sciences – the change of state in the physical environment – and those belonging to the domain of the social sciences – society and its norms. The definition thus also reflects what should have been obvious anyway, that environmental problems require a multidisciplinary approach for their solution. We shall turn to an analysis of how such a multidisciplinary approach might help to solve environmental problems, but only after we have examined in some detail the origins of our current environmental predicament.

2.4 How did our environmental problems arise?

From the Neolithic Revolution to the dawn of the Industrial Age

Section 2.2 discussed in admittedly schematic terms the way natural ecosystems operate, i.e. the way in which energy and raw materials are transported through food webs. How do human activities fit in with this? Human hunting and gathering societies pose no problems. After all, hunter gatherers alternately play the parts of herbivores, predators and prey. It has been calculated that had humanity continued to live this way, the total human population would have consisted of about 10 million people. In 1990, however, the human population was an estimated 5321 million. Such a hugely increased population size immediately prompts us to ask the following two questions: 'What allowed such a tremendous population growth to occur?', and 'What are the limits to the human population the Earth can support?'.

In order to find answers to these questions we need to go back in time and examine the development of human society. It is over 10,000 years ago that humanity changed from a hunting and gathering lifestyle to agriculture. The driving force behind this development is largely unknown. Some archaeological sources suggest that the increasing scarcity of large animals may have contributed. In addition, climatological changes occurring after the end of the last Ice Age (about 18,000 years ago) probably played a part. As these developments took place in the Neolithic period, the transition from a hunting and gathering lifestyle is sometimes described as the Neolithic Revolution. This revolution probably continued for thousands of years and did not take place simultaneously everywhere on Earth.

The most ancient farms have been found in the Middle East, in a region where wild wheat grew naturally. It is likely that people started to collect grains of corn and to use part of the harvest as sowing-seed for the next growing season. In Mexico, beans and maize were already being cultivated 8000 years ago. Societies also started to develop cattle breeding by letting tamed, wild animals reproduce in captivity. Together with agriculture and cattle breeding, the need to develop techniques for food conservation arose and this most probably stimulated pottery. In the same period, humanity also invented the wheel – which facilitated transportation – and started to use metals like copper and bronze for tool making. The use of these new tools, of course, further improved agricultural techniques.

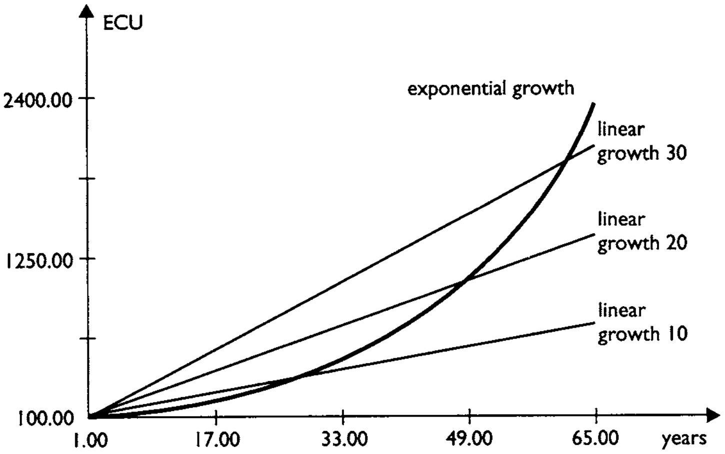
The Neolithic Revolution is usually not regarded as a severe threat to the ability of the biosphere to sustain itself. Even though soil erosion, pollution, deforestation and land degradation did occur where human settlements arose, sunlight still provided the primary energy source and people and their crops still neatly fitted into the natural

3

Linear versus exponential growth

Suppose you have a sum of money (say, ECU 100.00) that you do not immediately need. You therefore decide to put it in a savings account with your bank. Rather than offering you the regular deal of a fixed interest rate (say, 5%), the bank makes you a special offer: a fixed annual sum (ECU 10.00) which in the first year exceeds the sum you would obtain had you chosen the regular deal (ECU 5.00). Asked to consider the offer you wonder whether this indeed is a good deal. The correct answer is 'it depends'. It will be intuitively clear that, profitable though the deal initially may be, after a number of years you will lose on it as the interest on your growing sum exceeds the fixed amount you receive (in this case, after 28 years). So whether it is a good deal depends on how long you plan to leave your money in the bank.

This example illustrates the difference between linear and exponential growth. The ordinary deal with a fixed interest rate makes your capital grow exponentially as each year a fixed fraction is added; the special deal is an example of linear growth as each year a fixed sum is added. However large this fixed sum, at some point of time exponential growth is bound to overtake linear growth. The reason is that with exponential growth the amount of increase in a certain period of time itself becomes eligible for growth. You get 'growth on top of growth', so to speak.



Exponential growth is fast, much faster than most of us intuitively expect. The trick of it is that it gets faster as it goes (see the curved line in the accompanying graph). This is why exponentially growing processes are so deceptive. Doubling the fixed sum of ECU 10.00 to 20.00 makes a difference. But it only helps for an ever shorter while: now after 22 more years the point is reached where an ordinary, interest rate deal is the better one (compare the two lower straight lines). And if ECU 30.00 were to be offered 12 more years would suffice to reach that point (top-most straight line). So the time needed for the exponentially growing sum to overtake the linearly growing one increases, but less and less so.

Malthus was one of the first people to appreciate the distinction between exponential and linear growth.

geocycles. What infringements did occur had a minor and non-lasting impact, owing to the relatively small size of the human population. They could be accommodated, it is believed, by the biosphere's inherent abilities to adapt and restore. This does not apply to the second revolution, that originated in Europe.

In the beginning of the Christian era, about 37 million people were living in Europe. By about 1500, Europe had 70 million inhabitants and after 1650 the population rapidly increased. The reason for this rapid population growth was that, as a result of improved agricultural techniques, a relatively large amount of food was produced. Therefore, a product like wheat was cheap, people were better nourished and thus had an increased resistance to disease. As a result, population growth increased rapidly. This implies that a growing number of people needed food, clothing and housing. In addition, a growing number of people needed employment in order to earn a living. However, agriculture did not offer sufficient employment because of low prices, and trade only provided work for a limited number of people. Thus the perspective in those days was not rosy. According to the English clergyman and economist Thomas Robert Malthus (1766–1834) it would be impossible to provide the ever-increasing population with food. In his essay *The Principles of Population and its Effects on Human Happiness* (1798) he argued that there was a tendency for the population to increase exponentially, to double about once in every 25 years, while the means of supporting the growing population, growing linearly, could never keep up with this pace (see Box 3).

War, famine and catastrophes, however, would continually reduce the size of the population to a level which could be supported. According to Malthus, this mechanism would mean that the standard of living of the majority of individuals would never surpass mere subsistence. Others argued that the advance of science and technology would bring humanity prosperity and opportunities for personal development. The jury is still out on whether indeed science and technology will in the end bring prosperity for all. However, the optimists at least have proved to be correct to some extent in that science and technology have been able to suspend or alleviate Malthus' doomsday scenarios. In the countries of the North, the Industrial Revolution of the 18th century and the ensuing Agricultural Revolution have been successful in banishing famines almost completely. In the developing world, the Green Revolution of the 1960s was instrumental in providing food for many more than previously, thus ridding a country like India entirely of famines.

The Industrial and Green Revolutions

In the English society of the middle of the 18th century, spinning and weaving were mainly cottage industries, carried out in the countryside during the winter season. The products made by spinning and weaving were sold to travelling merchants. The increasing demand for textiles arising from the increasing population size resulted in an interference with the textile cottage industry by these merchants. First the merchants started to provide the cottage workers with raw materials. The products made from these materials were collected after an agreed period. Later the degree of organisation of their activities increased still further. The merchants (entrepreneurs) started to hire buildings and made textile labourers work under supervision and for fixed periods of time in factories.

At first, the most important source of energy in the factories was muscular strength, sometimes supplemented with water and wind energy. This situation dramatically changed after the development of the steam engine by the Scottish engineer James Watt. Its development resulted in an increasing demand for machinery, coal and iron. Industrial production necessitated transport and stimulated both the development of means of transport and the associated infrastructure (such as roads, warehouses, etc.). An industrial development was set in motion which has continued until the present day. Thanks to this development, the primary necessities of life such as nutrition, clothing, housing and medical care are increasingly provided for, at least in the prosperous countries mainly located in the northern hemisphere. In addition, luxury products, leisure time and opportunities for travel have increasingly become available, again predominantly in the prosperous countries. The lifestyle in these countries is now completely different from that of the 18th century European citizens and hardly bears any resemblance to that of our hunting and gathering ancestors.

Since the Second World War there have been revolutionary changes in agriculture. These have centred on the development and cultivation of new, high-yield hybrid crop varieties. There are many such varieties which have vastly improved yields and productivity in Europe. Cultivation of these new varieties goes hand in hand with the use of fertilisers, irrigation and herbicides, fungicides and other pesticides. New crop varieties and accompanying technological changes were also introduced to many developing countries (for example, new rice strains in South East Asia or maize in Latin America) in a process called the Green Revolution, though, in many areas, these changes had adverse environmental impacts.

These agricultural changes have been more successful in delivering food in areas where an infrastructure already existed and could be stimulated than in areas where these favourable conditions were absent. The increased yields resulted in economic and social developments within these agricultural societies and created employment in the food industry and distribution services. People's lifestyles were dramatically changed also, particularly in the rural areas. Essentially the agricultural and industrial changes altered the natural transportation routes of energy and the natural geochemical cycles. The question of prime concern to us here is what the environmental consequences of these changes have been.

The impact of social changes on natural processes

In order to answer this question properly we need to appreciate that the Earth is a closed system. A closed system is one that exchanges energy with its environment but not matter. The Earth is such a system because it exchanges energy with its surroundings (outer space) but the total amount of matter on the planet for all practical purposes remains constant. The description of the biological model of living Nature in section 2.2 revealed how solar energy was trapped and converted into chemical energy by the process of photosynthesis in autotrophic organisms (mostly plants). Solar energy is 'stored' in biomolecules and released when necessary. Release can take place not only in the plant itself, but also in an organism that has directly or indirectly fed on the plant. Thus, all living organisms use solar energy, directly or indirectly. Living organisms are very skilful at converting energy from one form to another.

Industrial production processes also convert energy. The efficiency of these energy conversions, however, is (still) a far cry from that of natural processes. It is not only the efficiency of natural energy conversions which deserves our attention; we should also consider their economy. Living organisms only produce the materials they need in order to function, and hence use energy in a highly economical way. When the energy balance is positive, energy is stored in compounds such as starch, glycogen and lipids. Each living organism degrades biomolecules that have fulfilled their biological function to smaller units and subsequently uses these for the production of new biomolecules or as a cellular fuel. Moreover, the biomolecules present in an organism can, after the death of this organism, be used by other organisms, especially micro-organisms. Industrial production processes tend to be much more wasteful.

While the efficiency with which energy is converted and the economy with which it is used constitute a significant difference between natural and industrial processes, both processes also differ in the kinds of materials and energy they use. Natural production processes mainly use the elements carbon, hydrogen, oxygen, nitrogen, phosphorus and sulphur, in addition to very small amounts of other elements. Processes designed by humans, mostly aimed at fulfilling social desires, use practically all elements present on Earth and also ones outside the natural geochemical cycles. This often implies that, when a product is no longer needed, degradation of dumped material by micro-organisms, Nature's janitors, is difficult or even impossible.

Even in producing materials, involving the elements commonly found in biomolecules, we often use processes which make the products virtually non-biodegradable. For example, the polymerisation of molecules (creating chains of the same molecules) using free radicals (highly reactive chemicals) to produce plastics, and the halogenation (addition of fluor) of organics to produce pesticides involve processes alien to biological systems. Free radicals, for instance, are highly damaging to living systems because of their reactivity. The use of such molecules in production processes, particularly in unnatural reaction conditions (for example, very high temperatures and pressures), leads to products that are completely 'unknown' to living systems. Unlike bioproducts, these products often are effectively untouched by geocycling, which leads to their accumulation in the environment. As we all know, accumulation of dangerous substances poses various environmental problems, to put it mildly.

The types of energy used in industrial production processes also differ from those in natural processes. As was explained above, solar energy is directly or indirectly converted to chemical energy in Nature. Biomolecules thus contain a certain amount of energy stored in a huge variety of compounds of the element carbon. The energy can be released again from the carbon compounds by oxidation. This oxidation principle is used by living organisms during the biologically controlled energy-yielding reactions of metabolism. On a large scale it is applied during the combustion of fuel in human-made production processes. Not only is the efficiency of combustion far lower than that of natural 'combustion', but unwanted side reactions take place that do not occur in living Nature. The products resulting from such side reactions often have negative effects on the environment.

The environmental consequences of human intervention

When a living organism dies, it stops converting and storing energy, but the reduced carbon compounds still exist. They can be used by other organisms. This does not, however, always happen. Under favourable geological conditions, this organic material can be converted into gas, oil or coal. In this way huge amounts of solar energy have been stored in these three fossil energy sources. What humanity began to do on a large scale around the middle of the 18th century was to maintain human society at the expense of these energy reserves. We are, however, rapidly exhausting our energy resources and the adverse environmental effects are becoming more and more evident. In satisfying its needs and wants, humanity uses practically all elements present on Earth and the Earth's energy resources. Matter is thus converted from one form into another, usually at the expense of much energy. Matter is not lost during conversion and can, in principle, be recycled, but again at often considerable energy costs. But the situation is completely different as far as the energy resources are concerned; fossil energy is simply being exhausted.

Plate 2.2 Exploitation of non-renewable energy resources: winning of natural gas in the North Sea off the Dutch coast. Photo: Rob de Wind

So even if at present we can keep 5321 million individuals alive on Earth, this situation cannot last forever. Problems may arise in two fundamental areas. Given that the total amount of matter on Earth is constant, the production of materials which are not easily recyclable (either biologically or by human activity) means that the pool of resources is being depleted. If, at the same time, the accumulated products have undesirable properties (for example, in that they are toxic or carcinogenic or cause the climate to change), then their production, use and dispersal become key environmental issues. These problems are exacerbated through population growth, because more materials are produced, resources are more rapidly depleted, etc. Important though these issues are, the more crucial issue is ultimately that we should not use more energy than is entering the system. How can we trap, convert and store the energy that is entering the Earth's system and how much of it can we trap? The use of autotrophic organisms – i.e. plants, algae, etc. – would at first sight seem to be a viable option. It means that agriculture should redirect its mission from primarily food production to food and energy production. This would mean a revolutionary change in agricultural practice.

Interestingly, the last four to five decades have already witnessed an agricultural revolution that has greatly increased food production. But for all these benefits, there have been and still are negative effects. Although they are not our primary concern here, some of these are negative social effects. The development of new high-yielding varieties is expensive and, in the absence of international aid, remains beyond the reach of poor farmers in developing countries. This further widens the gap between the rich and poor countries. Our prime concern here, however, is the negative environmental effects. The modern agricultural revolution owes its success to a large extent to the abundant use of fertilisers and crop protectants (herbicides, fungicides and other pesticides). Insects and pathogens, through evolutionary changes, may develop and have developed resistance against crop protectants. Their use thus makes the fight against pest animals even more difficult and often also more expensive. This effect is further exacerbated by the trend in modern agriculture to produce ever larger monocultures, thus reducing genetic diversity and increasing the vulnerability of crops to diseases and pests.

Modern agriculture also consumes much fossil energy. The production of herbicides, fungicides and other pesticides requires energy, as do irrigation and mechanical treatment of the soil. The manufacture of the machines used to plough soils, deliver fertilisers, and apply crop protectants also requires energy, as does their transportation. The result is that agriculture is now responsible for about 5% of world energy consumption. This energy use has negative environmental effects, as we have already discussed above.

In summary, both the Industrial and Agricultural Revolutions have brought prosperity to the developed countries and, though to a much lesser degree, to the developing countries. They could only achieve this by significantly altering the natural environment. Not all these changes were for the better, though. Indeed, there is a general consensus that many changes prompted grave environmental problems, in both the developed and developing countries.

Mineral resources were and still are being used in a wasteful way. Hence they will be depleted, and so will our fossil energy resources, even though in some cases new resources are discovered at a faster rate than existing ones are depleted. Metaphorically speaking, we are living off the dowry the Earth has provided us with and pretty soon nothing of it will be left for our children to inherit.

Even worse, perhaps, we are rapidly polluting the environment, making it less habitable for us humans, for our fellow creatures and for our and their offspring. And to make the picture yet grimmer, developing countries justly claim their share of the developed countries' prosperity. Were they to obtain it the way the developed countries have, an environmental disaster is inevitable; on the other hand, were the developing countries to be denied their share – if that is at all conceivable – a social disaster looms large.

2.5 Environmental problems: preventing and solving them

Overcoming our environmental predicament means no less than abandoning wasteful and polluting behaviour in a way that is fair to both the developing and developed world. What this boils down to is achieving a sustainable development on a worldwide scale.

The question of how exactly one might do that is a large one, too large indeed for this chapter (but see Chapter 7 for more on this subject). Scientific knowledge, however, should play a part in its answer. How, in general terms, it does so is the subject of this section.

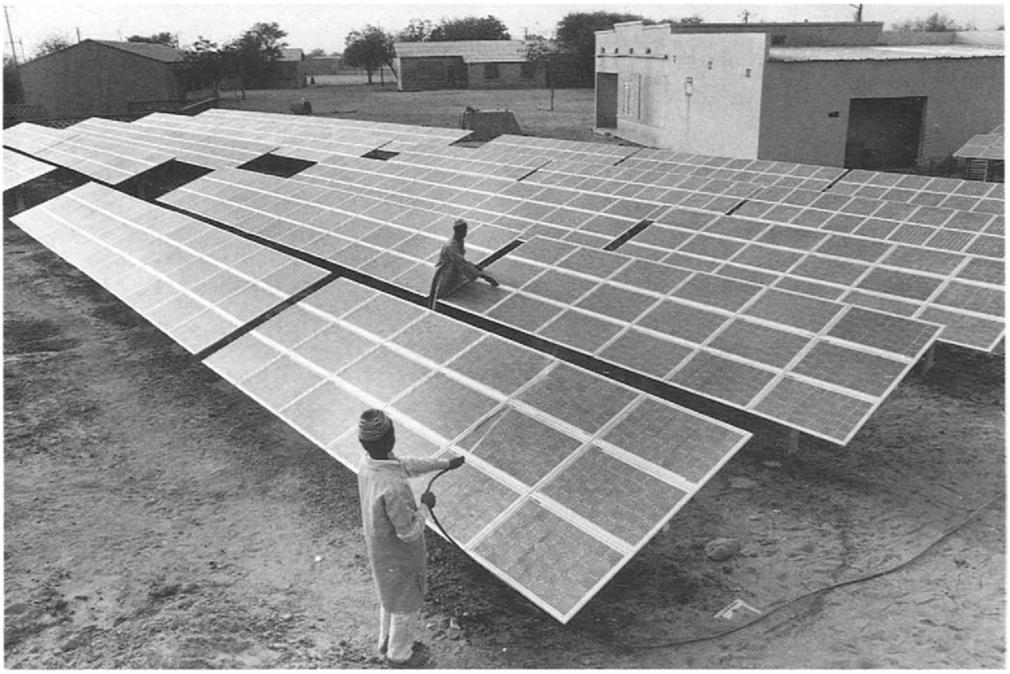


Plate 2.3 Renewable energy: solar energy for a hospital in Gao, Mali. Photo: Ron Giling/ Lineair

In section 2.3 we concluded that environmental problems arise out of the interplay between actions belonging to the domain of the natural sciences – the change of state of the physical environment – and actions belonging to the domain of the social sciences – society and its norms. Similarly, solutions for environmental problems need to tap into both scientific and sociopolitical knowledge, while looking for guidance from the norms that society entertains. Understanding this tripartite interaction requires the adoption of a decision theoretical framework. What this amounts to is best understood through the examination of a concrete example first. We will therefore return to the ozone example, touched upon in section 2.3.

The depletion of the ozone layer

It is almost universally agreed that the release into the atmosphere of chlorofluorocarbons, CFCs for short, is by far the greatest cause of the depletion of the ozone layer. CFCs are widely used as coolants in air conditioners and refrigerators, but also as cleansing agents for electronic circuitry. They are cheap and chemically almost inert, two factors that explain their wide use. The story changes, however, in the upper stratosphere (see Figure 2.3). At that level, there is a thin layer of ozone, a highly reactive form of oxygen. It is formed through the action of solar radiation upon ordinary oxygen molecules. Ozone is also formed in the troposphere, the lowest stratum of the atmosphere, but at that level it reacts instantly with other molecules and hence disappears quickly. In the stratosphere, however, there are not many molecules to react with, resulting in the build-up of a thin layer of ozone. This layer is of great importance for life on Earth in that it prevents nearly all harmful solar radiation, the so-called UV-B radiation, from reaching the Earth.

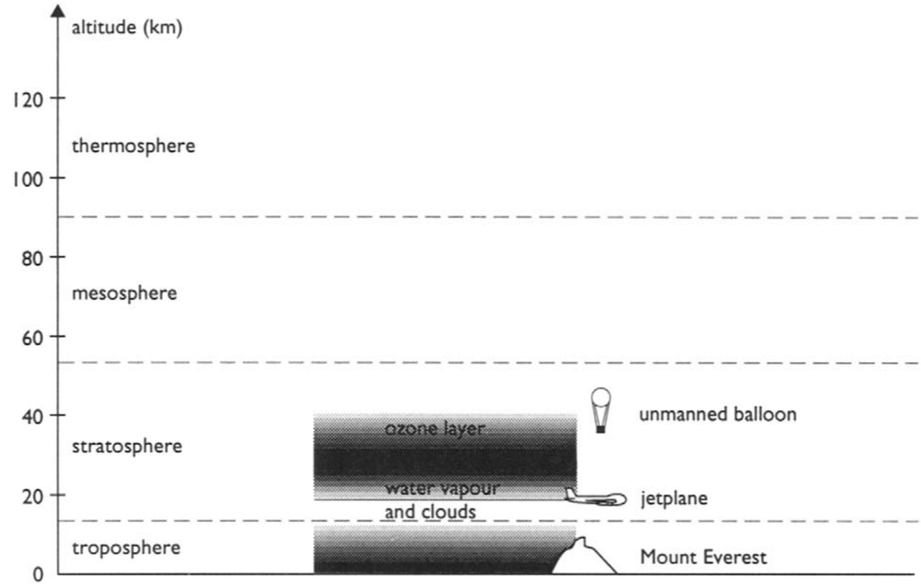


Fig. 2.3 The layers of the atmosphere.The ozone layer is confined to the lower stratosphere, with the ozone concentration peaking at an altitude of about 25 km.

However, the CFCs introduced by humanity in the lower atmosphere have slowly leaked into the upper stratosphere and have affected the ozone layer's protective potential dramatically. The chloride in the CFCs reacts with ozone and changes it back into ordinary oxygen, which is a much less effective absorber of UV-B radiation. To make things worse, the chloride acts as a catalyst, that is, after having reacted with an ozone molecule it is still available to engage in reactions with yet other ozone molecules. The net effect of all this is that the 'thickness' of the ozone layer (more precisely, the concentration of ozone molecules) will be reduced for years to come, the more so as it takes about 15 years for CFCs released in the atmosphere to reach the upper stratosphere.

What we have described so far, solely in chemical terms by the way, are the first order effects of the human introduction of CFCs into the atmosphere. We have traced effects up to an increased intensity of UV-B radiation. But the story does not end there as the increased UV-B in turn causes its own effects. Exposure of the skin to UV-B radiation may lead to the emergence of skin cancer; the more intense the radiation the higher the probability. At the level of an entire population, this translates into an

Modelling the ozone hole

4

Any mathematical model that seeks to show, for example, the damage done to the stratospheric ozone layer by CFCs should start with a description of the normal situation. Once the adequacy of such a model has been established, one may incorporate CFCs into it and try to explain and predict their effects.

A description of the normal situation is already quite complex. First of all, it should incorporate a large number of chemical equations. Because of the reactivity of ozone one cannot restrict one's attention to oxygen (out of which ozone is formed) alone, one also has to take into account the effects of molecules that occur in small concentrations only (hydrogen, nitrogen, naturally occurring chlorides). Secondly, some of these reactions are photochemical reactions, others are thermal reactions. Photochemical reactions depend on the intensity of the light and, as light intensity varies seasonally, diurnally (daily) and by latitude, the model has to take into account these three variables too; thermal reactions depend on the temperature and, as temperatures are altitude and latitude dependent, models should also consider these variables. Thirdly, reaction products are often transported, vertically and horizontally. Effects of such transports should therefore also be accounted for in a model.

A model that takes heed of all these complications becomes unmanageably complex. Simplifying assumptions therefore have to be made and are being made. It has been proven that such simplified models are quite well able to describe the natural ozone concentrations at various altitudes and longitudes. Such models have also been shown to be able to incorporate the effects of humanly released CFCs, although specific situations such as those occurring at the poles require specific models.

Sources: the above description is based on the moderately technical treatments found in Phillips (1988) and Sherwood Rowland (1988). More accessible but nonetheless comprehensive treatments can be found in Chapter 5 of Meadows *et al.* (1993) and RIVM (1992).

increased incidence of skin cancer, as indeed it has in Australia and New Zealand (see Figure 2.2). Another effect of the increased intensity of UV-B radiation is a more rapid degradation of plastics; yet another is the altered migratory behaviour of planktonic algae, affecting primary production in coastal waters and ultimately the size of fish stocks. It is these ultimate effects that for various reasons – ethical and economic – we deem problematic.

The world community has reacted with amazing speed to the threat of increased intensities of UV-B radiation. In 1987, a protocol was signed at a conference in Montreal, with the intent of taking measures to protect the ozone layer. The protocol demanded levels of the major CFCs to be kept at 1986 levels until 1993. After 1993 a gradual reduction was to take place. However, model predictions soon revealed that the levels of CFC emissions admissible according to the Montreal protocol would not sufficiently protect the ozone layer. In fact, calculations showed that chlorine concentrations would keep rising, as a consequence of which the ozone layer would probably end up being entirely depleted. Under the guidance of UNEP, the United Nations Environmental Programme, a new, more stringent agreement was signed in London within a year after the Montreal protocol. Under this agreement, chlorine levels should start falling around the year 2000, which is when the current amount of tropospheric ozone will reach the stratosphere and start to leak away from there.

Decisions and models

Clearly, the decision to cut back on CFCs was taken on the basis of model predictions fuelled by the broadly felt unacceptability of increased UV-B radiation intensities. How did this decision come about?

We will not provide a sociopolitical analysis – such is left to chapters to come. Rather, we will try to understand how in a formal sense scientific models and public norms interact to produce decisions. For this we need some elementary decision theory. The benefit of such an admittedly unrealistic approach is that it provides the backdrop for actual policy making. Of course, our treatment here will be elementary and only aimed at elucidating the principles at work.

In decision theoretical terms, then, cutting back on CFCs is an *action*. Actions have particular *outcomes*, depending on the kind of system acted upon; in the CFC case some local ozone concentration would qualify as an outcome. (Actually, things are a bit more complex as it only makes sense to talk about an ozone concentration at some altitude and latitude at some specific point of time; we shall ignore these complications; see Box 4.) A *model* of the system allows one to figure out what outcome some action will have (see Figure 2.4). Depicted this way, decision processes look quite simple: given a particular agreed upon outcome, the model at hand dictates which action to take. This picture, however, is too simple in at least two ways.

One should never consider singular actions. Different actions usually will have different outcomes and one should evaluate and compare several actions with respect to their outcomes. After all, the first action considered need not be the best one. When one considers the Montreal and London protocols as actions – and one may justifiably do so even though their outcomes were evaluated consecutively rather than simultaneously – they aptly illustrate the principle.

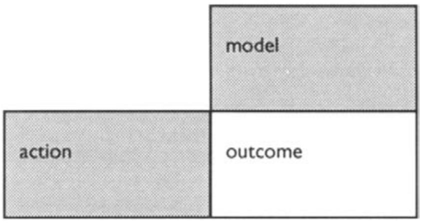


Fig. 2.4 A simplistic decision matrix.An action results in a particular outcome,given some model. Choose the action in such a way that it produces the outcome desired.

Evaluating outcomes with respect to their desirability, however, presupposes the existence of some yardstick. Outcomes in and of themselves are unfit for this; they are just particular states of the system under consideration, such as particular local ozone concentrations. In decision theory, outcomes are evaluated with respect to each other by attributing *utilities* to them; the outcome with the highest utility is the one most preferred. So the outcome of actions taken under the London protocol has a higher utility than the outcome under the Montreal protocol, precisely because we value higher ozone concentrations more than lower concentrations.

We will not delve too deeply into the question of how exactly one arrives at utilities for outcomes. Two observations need to be made, however. First, and not surprisingly, different outcomes should have different utilities. Otherwise, the utility scale chosen would be unfit for comparing outcomes. Second, and more importantly, in the final analysis all comparisons between utilities are founded upon some normative stance. In section 2.3 we already argued that environmental problems contain an element of convention: agreed upon norms are essential in calling some issue an environmental *problem*. Now the time has come fully to deliver on this qualification: what utility scale one adopts in the effort to solve some environmental problem ultimately depends on the particular normative stance one takes.

As we saw, in the ozone case norms used may be premised upon such diverse considerations as unnecessary human suffering or excessive economical damage. Much as in the phase of a problem's definition, how basic ethical rules get translated into utilities is subject to a process of negotiation that takes place in the sociopolitical arena. In democracies this is usually formalised and often cumbersome; in dictatorial states hardly any negotiations take place. Even so, whether for the benefit of all or for that of the powerful only, ethical considerations (or the lack thereof) play their part. Indeed, some argue that the quality of such processes of translation would benefit greatly from a more explicit incorporation of ethical principles (for more on the subject of the role of 'practical' ethics, see Shrader-Frechette, 1991, 1994). This is an important conclusion as it undermines the often-voiced conception that science alone would suffice to solve environmental problems. As we shall see shortly, this conception is to be criticised on yet other grounds.

So far, the impression has been given that *one* model would do to predict the outcomes of actions. This, however, is seldom the case. More often than not, a variety of models are in use and scientists disagree over their reliability, applicability, validity, accuracy, etc. This is hardly surprising. By their very nature, models capture reality

5

The limits of scientific knowledge

Knowledge about the world is generally captured by models (or theories, laws, hypotheses). Such empirical knowledge is fallible, as the philosophy of science has established beyond much doubt. Models, however well confirmed, may turn out to be mistaken, as the history of science amply illustrates. This implies that the prediction that some action results in an outcome is only as good as the models used to generate the prediction. Models, furthermore, need data in order to connect actions with outcomes. Models use functions in which parameters feature for which in turn numerical values are needed. Also, the state which the model is in at some particular starting time, say t_0, has to be characterised, meaning that numerical values for the state variables (the variables characterising the model's behaviour) are required at t_0. These values could either be measured directly or inferred through other models which in turn rely on data that are either measured or inferred from models which .... Such data are not absolutely reliable.

If they have been inferred, they result from computations that may employ mistaken models. If they have been measured, measurement errors may have occurred. Indeed, one may justifiably claim that *all* data are in a sense inferred, because knowledge of the functioning of measurement devices rests on models. It may now seem that scientific knowledge is hardly useful in environmental decision making but such a conclusion would be a serious mistake. The above lines of reasoning apply to all empirical knowledge, from natural or social science or other sources. Hence, whether we like it or not, our powers of control over the world are limited in a fundamental, epistemological sense.

There are, however, also more prosaic reasons why our knowledge of the world is limited. First, some perfectly deterministic models – models in which no chance effects occur – may yet not allow one to know their future states at all. The reason is that such models exhibit chaotic behaviour, meaning that an ever so slight imprecision in their initial state implies an almost total ignorance of that system's future states. Secondly, stochastic models, i.e. those that do harbour chance effects, involve predictions about future states which take the form of probability distributions over the system's set of possible states.

Both these reasons constitute limits to our powers of control that operate at the theoretical level, but there are also limits that operate at a more pragmatic level. First, as was already argued above, data are needed in order to specify numerically parameter values and initial conditions. However, there could be problems in obtaining these data. Perhaps the necessary experiments are unethical, perhaps they are too costly, perhaps they take too long. Any one of these limits may imply that one has to work with estimated or, even worse, guessed data. Second, when models also make assumptions about the social behaviour of people – and models that include the implementation of measures always do – the possibility has to be included that people react to measures taken. That is, the very measures that a model recommends may prompt people to behave in certain ways that differ from the way the model in the first place assumed them to behave. Unless one alters the model accordingly, such reactions invalidate the model. However, incorporating reactions is notoriously difficult. Doing it tends to complicate models beyond control; not doing it seriously affects their value. Unfortunately, there is no easy way out of this dilemma. The upshot is that scientific knowledge, whether social or natural, has its limits, epistemological, theoretical and pragmatic. But that, of course, should not keep us from using the models in which such knowledge is embedded.

Source: Doucet and Sloep (1992).

only in part. They make all kinds of simplifying assumptions, and they have to, otherwise they would become unmanageable (see also Box 4). An issue for discussion, of course, is what simplifying assumptions to make and how these affect the model's performance. Also, one may argue over parameters. In principle, they are constants needed to do the calculations (arrive at numerical predictions). However, their exact values are often disputed. Indeed, one may challenge the assumption that some parameters are constants at all and argue that they actually should have been incorporated in the model as variables. Sometimes, the very structure of a model is under dispute. Particularly, when the implementation of measures is incorporated in a model and social structures therefore are to be taken into account, many alternatives may be considered (see Box 5 for an elaboration). All in all, there seems to be ample room for disagreement over models. In almost all decision processes, therefore, various models will be considered.

This may have far-reaching consequences, depending on the kind of decision situation at hand. One makes decisions in complete certainty, limited uncertainty, and complete uncertainty. The first category poses no problems as, in fact, one is dealing with a one-model decision problem. The second category hardly ever obtains in environmental decision making, as it seldom occurs that one has the required numerical estimate of the likelihood of application of the models involved. The third situation occurs frequently and we will illustrate it here through the ozone case. Unfortunately, this case does not lend itself optimally to illustrating these matters as alternatives were considered consecutively rather than simultaneously. Discussions about the suitability of the models used therefore did not really arise. (It was effectively a decision problem with complete certainty.) We will use it nevertheless by making some counterfactual assumptions.

Decision rules

Suppose, for the sake of argument, that the Montreal and London protocols were considered simultaneously and that two models, based on two different data sets, were available at the same time. Furthermore, suppose that one had no way of deciding which one of the models was the better one. Figure 2.5 illustrates this situation. In it, utilities have been ranked with number 1 as the most preferred outcome and number 4 as the least preferred outcome.

The utilities are awarded according to the following two rules, rule 1 taking precedence over rule 2 (outcomes are assumed to be in the form of ozone levels):

- *Rule 1*: the ozone level which is on target gets the highest rank; ozone levels above target get higher ranks than ozone levels below target. The rationale behind this is that, once a target ozone concentration has been agreed upon, higher ozone concentrations are better than lower ones in terms of the damage done by the UV-B radiation.
- *Rule 2*: all other things being equal, ozone levels achieved under the Montreal protocol receive higher utilities than those achieved under the London protocol. Here the rationale is that, as the London protocol demands more extensive actions than the Montreal protocol, it is the economically more expensive one.

Presumably, outcomes (1,1) and (2,2) (see Figure 2.5 for the numbering convention) have identical ozone concentrations and hence identical utilities according to rule 1; rule 2 now makes (1,1) preferable over (2,2). Rule 1 also tells us that outcome (2,1) is to be preferred over outcome (1,2).

Now, notice that action 1 leads to outcomes with both the highest and the lowest utility rank (1 and 4 respectively), while action 2 leads to the intermediate ranks. However, no action is uniformly better than the other in that it gives the better result whatever model obtains: if model 1 obtains, action 1 is the better one, if model 2 obtains, action 2 is the better one. In cases like this one has to follow one of the following rules. Either *play it safe*, take no risks and choose the action that minimises the losses; that would be action 2 as it avoids the worst outcome. Or *gamble*, hope for the best, and maximise the gain; that amounts to action 1 as it picks the best outcome (and runs the risk of losing a lot).

What rule to pick is a matter that is external to the particular decision problem. One has to agree on it beforehand on the basis of some normative position one adopts with respect to the question of whether it is OK to gamble with the environment or not. In our present rendering, one might decide to stick to the original Montreal protocol and gamble that the model 2 predictions do not apply. No doubt, this would save industry – and hence us all – money. However, if the model 2 predictions turn out to be correct after all, we would suffer severe damages. There is a reason then why one might decide to play it safe and go for the more restrictive London protocol.

In actual fact, model 2, which is based on newer and better data, has replaced model 1. As we have said, the actual decision problem thereby has become one of complete certainty rather than complete uncertainty. Therefore, it suffices to look at the cells in the righthand column of the matrix only. And clearly then, action 2, the London protocol, is the better one.

But the ozone case is atypical. More often than not much battering goes on over the question of which model applies. Although lack of space prevents us pursuing this matter, the climate change case exemplifies this situation exactly. Cases like that typically conform to the decision problem depicted by Figure 2.5.

	model 1	model 2
action 1 Montreal protocol	1 (1.1)	4 (1.2)
action 2 London protocol	3 (2.1)	2 (2.2)

Fig. 2.5 A decision matrix for the adapted ozone case. Actions are protocols, models are models, outcomes are ozone concentrations. The large numbers represent ranked utilities for outcomes, 1 being the most preferred and 4 the least preferred outcome; the small numbers in brackets are used to identify outcomes.

In summary, the scientific knowledge embedded in models is crucial for reaching decisions. The present section has described why. However, it has also revealed the crucial importance of norms. Without norms it is impossible to attribute utilities to outcomes; and if the decision situation is one with complete uncertainty, it is furthermore impossible to choose between decision rules.

2.6 Conclusion

The ground covered by this chapter may conveniently be summarised by citing two dichotomies. In discussing environmental problems and the relevance of science for them, we have mixed specific facts and problems (sections 2.2 and 2.4) with general models and issues (sections 2.3 and 2.5); and we have contrasted the roles of science-based models and facts with ethics-based norms and values.

In conclusion we may say that, on the whole, science certainly has a solid contribution to make to understanding, preventing, and solving environmental problems. This conclusion holds irrespective of the normative character of environmental problems. At the same time, we should beware of putting too much faith in the natural sciences. Science-based recommendations have to be implemented, for which knowledge of society and its policy-making processes is indispensable. Chapters to come, starting with the next, will go into these matters.

Finally, the question of which policies to adopt willy-nilly reflects an ethical stance. Such ethical matters, implicit though they may be, are too important to be left to either scientists or politicians. They affect all of humanity, indeed the entire biosphere, and should therefore be the concern of all of humanity.