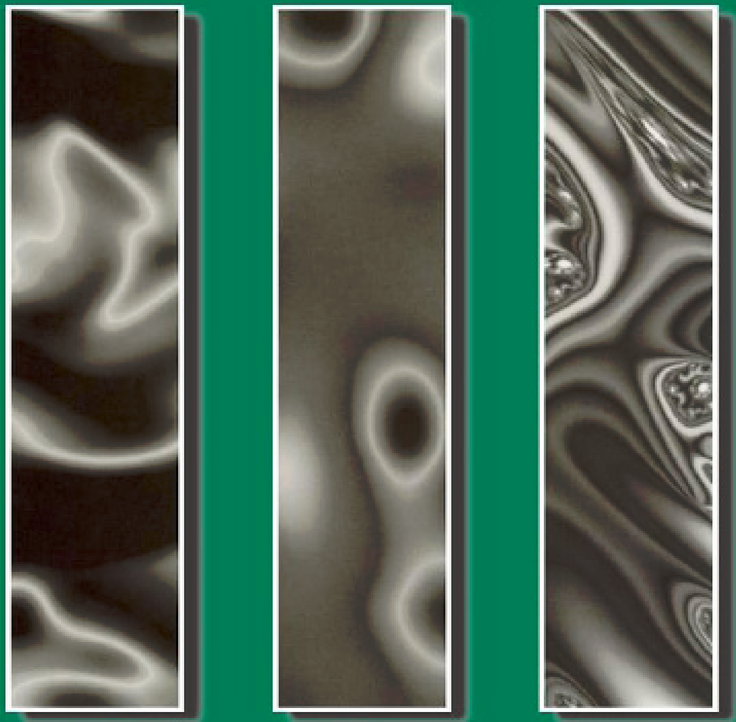

Principles of Environmental Toxicology

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DEDICATION

To my Mother, Father and David

I.C.S.

To Cath, Rebecca and Eleanor

J.C.

Contents

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1

Historical Review of Human Impact on the Environment

This chapter covers the evolution of pollution from the time when humans lit the first fire up to the present time when air pollution in our cities is beginning to affect human health.

Major pollutants (SO_2, NO_x, sewage) and agrochemicals (OCs and OPs) are discussed.

1.1 The Development of Pollution

In recent years humans have become more aware of their environment. This probably relates to the realisation that if we continue depositing our waste products at our current rate the environment, our world as we know it, will have a finite lifetime. The worry is, however, that the definition of finite might be measured on a scale that humans can relate to directly. It is for this fundamental philosophical (and selfish) reason that we are becoming interested in the effects of the chemicals that we use upon our world. This is the study of environmental toxicology. As with any science, what things do represents the fundamentals of understanding. In the case of environmental toxicology the action of chemicals upon environmental systems (ecosystems) forms the basis of the science. One hopes that having some, albeit very small, understanding of the effects of exogenous chemicals upon the inhabitants of an ecosystem might permit our predicting and perhaps preventing their deleterious effects in the future.

Generally the evolution of a scientific subject is slow, commencing with investigations of fundamental mechanisms, followed by an understanding of these mechanisms and moving to prediction and global understanding. Environmental toxicology is quite different. It has evolved on a fast track scheme, being driven by worries about the environmental devastation caused by human activity, fired by the green lobby and forced by legislation. For this reason we are being cajoled into predicting and acting before we understand the fundamentals of the subject.

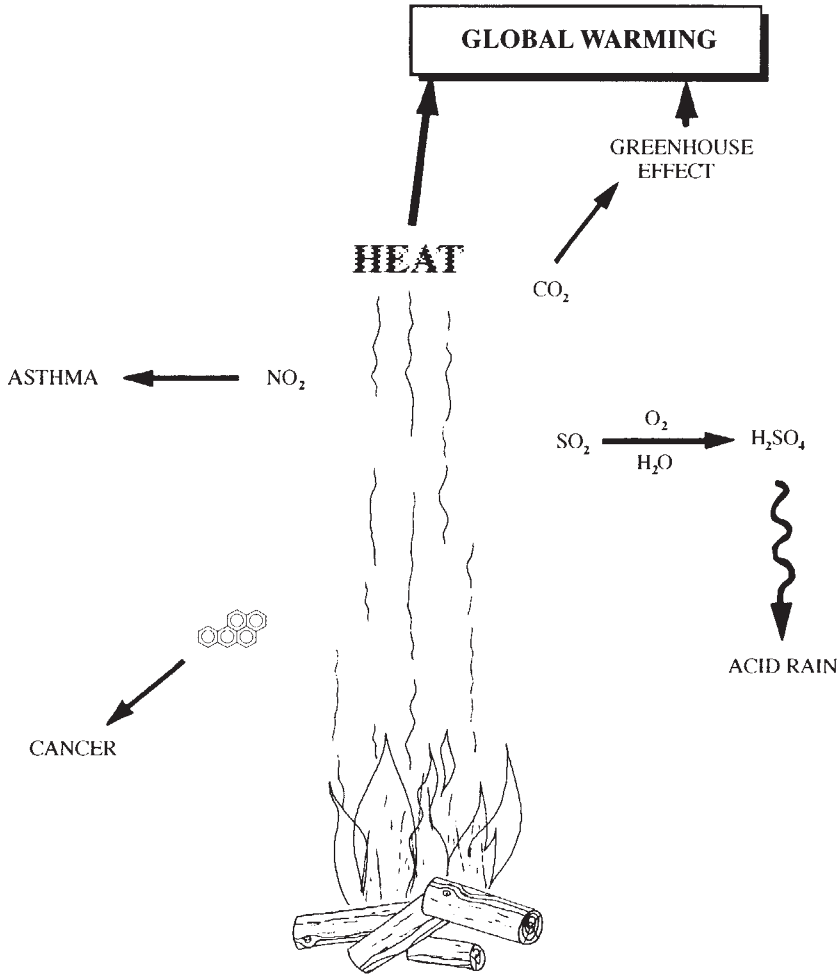

Figure 1.1 Generation of pollutants from fire .

Since humans evolved into a recognisable species about a million years ago their activity has modified the environment. Indeed it is a trait of humans that they not only evolved in a Darwinian manner, but also changed their environment to suit their needs. For example, in order to live in adverse climates people began to wear warm furs (these evolved into more complex clothes), they built homes and, very much later, dramatically extended their geographical distribution by developing air conditioning and central heating systems. Keeping warm in cold climates was an important step in human evolution. It was also a fundamental step in the acceleration of pollution. Fire produces carbon dioxide and other oxides (e.g. nitrogen dioxide, NO_2) (see Figure 1.1) which are

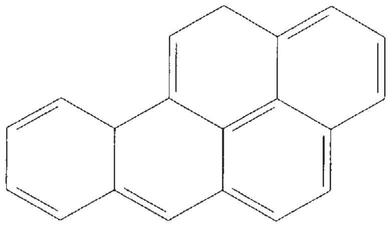

Figure 1.2 Molecular structure of benzo[a]pyrene, a carcinogen produced by combustion of carbonaceous materials.

important environmental pollutants. Both are dealt with in later chapters. The more esoteric product of the complex chemistry that occurs at the high temperatures within a fire are capable of significantly modifying the genetic material of both animals and plants. For example, benzo[a]pyrene, a polycyclic hydrocarbon (see Figure 1.2), modifies DNA resulting in mistranscription. In humans and higher animals this is likely to manifest as an uncontrolled division of the modified cell (cancer), whereas in lower organisms it is likely to result in genetically modified daughters. This modification, or mutation, might be beneficial or perhaps detrimental. It might give the organism an environmental advantage, weaken it or result in its death. This, of course, is the basis of evolution. Purists would say that fire is natural and therefore the whole process is biologically acceptable. This may well be so, but as the human population has grown and its dependence upon fire increased it is clear that the word *natural* might not be the most felicitous choice!

It is therefore clear that humans have, since time immemorial, polluted their environment and that this pollution adversely affected their co-inhabitants. Being philosophical, one might conclude that this adverse effect upon co-inhabitants of the environment is all part of evolutionary supremacy. That may well be the case, but we are now in a situation with some 4.5 billion human inhabitants of the earth in which the adverse effects upon the environment may well limit the further population growth of humans themselves or, even worse, force them into decline. This concept, of course, is nothing new in biology. We are well aware of the simplest organisms growing initially uncontrollably (log growth phase) (see Figure 1.3) and then reaching a peak of growth rate (the point at which their environment can only just support, in terms of nutrients, the population), followed by a brief plateau and then decline and eventual extinction. A fatalistic view is that people are simply following this profile and there is absolutely nothing that we can do about it. This very pessimistic view would certainly be the case if we were a non-thinking *Daphnia,* but people can think and plan and act to prevent pollution being the force which pushes them into decline. Optimistically, the fact that humanity's future depends upon protecting its environment will have a very positive knock-on effect to most other living organisms. At last we see the need to protect our environment.

The concept that an increasing human population is responsible for environmental decline is not entirely fair. Increasing population size in human

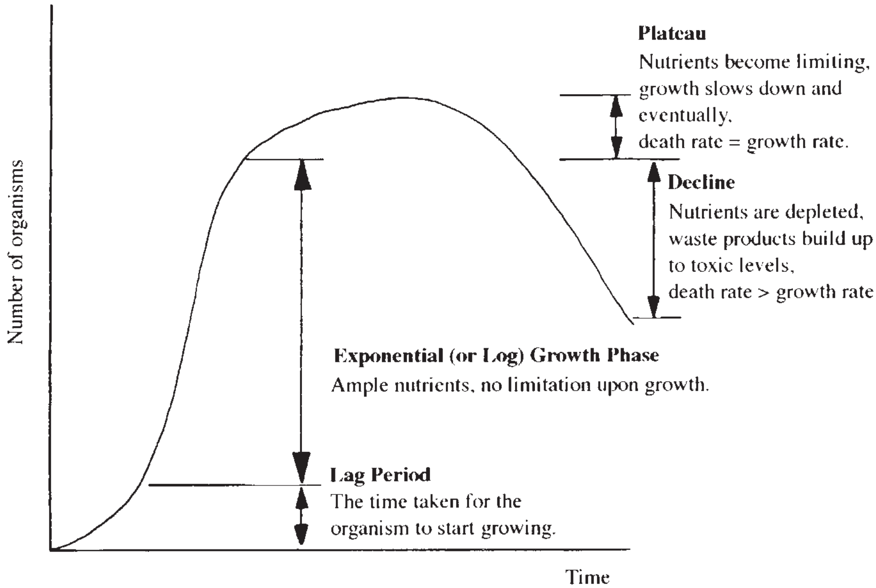

Figure 1.3 Graphical representation of the growth phases of a bacterial liquid culture. This equally well represents the population kinetics of any other species, including humans.

terms ran hand-in-hand with increasing knowledge and there came a point when humans became aware that some of their activities damaged either themselves directly or their environment. There are several examples of this realisation in Greco-Roman cultures (1100 BC–AD 565). The Greeks (560–333 BC) began intensively farming their crops. They grew fields of grasses and caged and fenced animals for food production. In order to get the best out of their land they used the manure from their livestock to fertilise their crops. This is one of the earliest examples of the application of nitrates to crops and was the precursor to our current problems with nitrate excess in water courses (eutrophication). We return to these issues later.

It is clear then that human occupation of the planet goes hand-in-hand with pollution; however, the level of pollution and the effect that this has had on the fine equilibrium of nature is what we must consider. Early human effects upon the environment were small and in most cases local. In general these local ecological effects were reversible. For example, the small amount of nitrate that the Greeks put on their fields could be washed away by rain and diluted by rivers to such a great amount that it would have no perceptible effect on the biosphere. This *status quo* was perhaps the case until population intensities became great. For example, the Aztecs developed a highly populated society which depended upon the potato as a dietary staple, the massive monocultures which resulted decimated the ecology of the region resulting in denutrification of the land and reducing crop yields. This was perhaps one of the reasons that the Aztec civilisation collapsed.

The most sinister date on the calendar of pollution is the commencement of the industrial revolution in the early 1800s. The industrial revolution marked the commencement of mass production, of mechanisation and (perhaps) of overproduction. This enormous increase in productivity meant waste. Factories sprang up in areas close to important elements of infrastructure (e.g. canals for the transport of raw materials), waste products were discharged into the immediate environs (e.g. the canals) without any thought at all. Soon industrial connurbations were flourishing. They were financially rich areas employing many people. Such developments pushed out wildlife. The pollution emanating from these industrial cities (e.g. Birmingham, UK) devastated the environment for miles around. So great was this devastation and over so long a time period that some plants and animals adapted in such a way as to give them an evolutionary advantage.

A classic example of this is industrial melanism. Coal was used to fire the blast furnaces, to heat the water to provide the steam to drive pistons and to heat the large number of homes that were essential to house the workers around the edges of industrial areas. Among other (perhaps more damaging) pollutants arising from coal burning was fine particulate carbon. This blew in the wind and coated buildings and trees (and people's lungs) with a black layer. Over a period of time the colour of trees on the outskirts of cities changed from mottled browns and greens to ubiquitous black. Animals who normally hid on their bark or among their branches had evolved over millions of years to resemble the brown/green mottled background. Suddenly the background had changed and they were easily picked out by predators. Moth populations were quick to adapt to this change in their environment and the melanic (dark) forms were selected for and became predominant. The melanic form blended in with their new background so making them less visible to their predators and allowing them to maintain their population. This is an example of amazingly rapid natural selection. It is perhaps the only example of natural selection which could be witnessed in the lifetime of humans. The most studied moth, in this respect, is the peppered moth *(Biston betularia)*. It lives on the silver and grey bark of birch *(Betula pendula)* trees and originally was mottled silver, white and grey itself (see Figure 1.4) in order to give it near perfect camouflage. Airborne carbon rapidly turned the silver bark black and made the moths visible to their predators. There was a rare dark (melanic) form of the moth which had resulted from an earlier mutation; this form was almost invisible on the newly darkened bark and so was selected into the population very rapidly indeed. Soon the melanic peppered moth became the most common form in industrial areas. In genetic terms the gene for melanism is dominant and so even the heterozygotes were dark; this of course speeded up the selection process significantly (see Figure 1.5).

The predominance of the melanic peppered moth in and around industrial areas was demonstrated by Kettlewell in 1973 when he reported the results of a

A

B

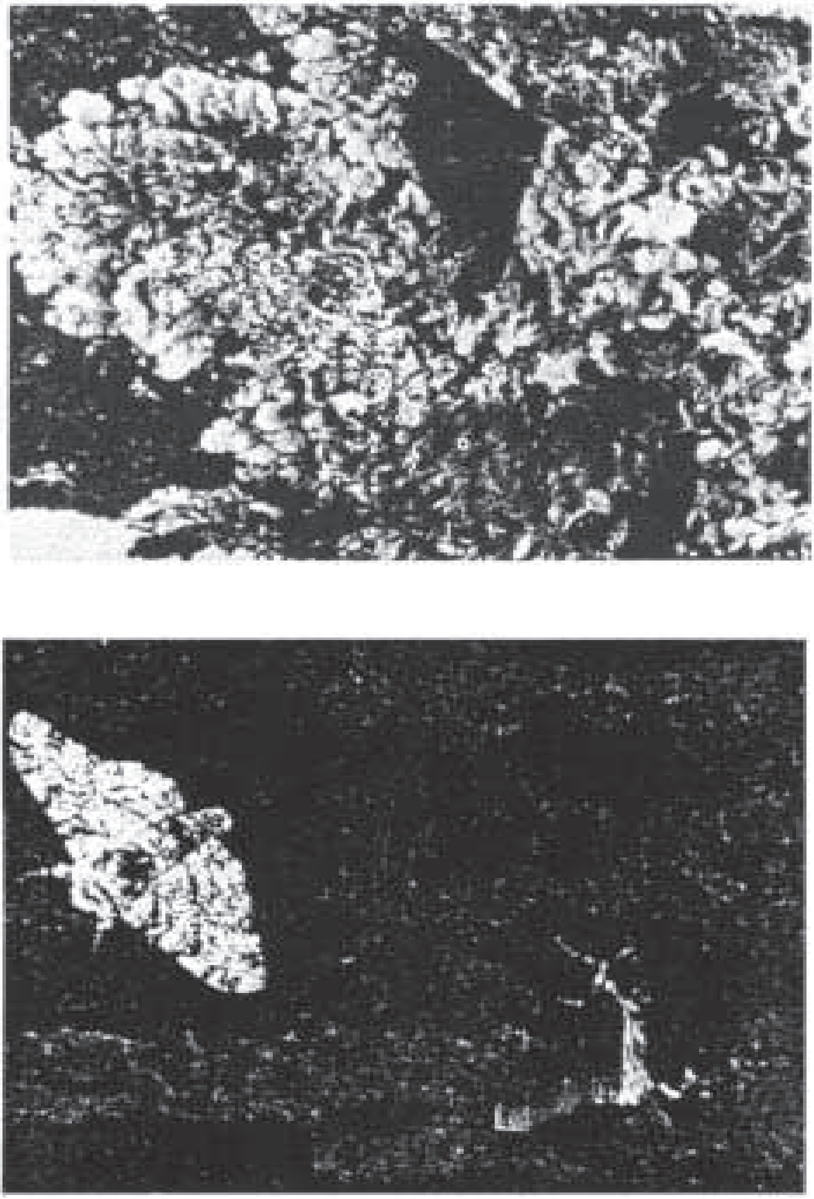

Figure 1.4 The peppered and melanic forms of *Biston betularia* on lichen-covered bark (A) and bark with carbon deposits (B). This shows clearly how well the melanic form is camouflaged on dark bark and the peppered form on lichen-covered bark. Reproduced from *Biology—a Functional Approach* by M.B.V.Roberts, with kind permission of Thomas Nelson Ltd, Sunbury-on-Thames, UK.

P_1	MELANIC **MM**	X	LIGHT **mm**	
F_1	MELANIC **Mm**	MELANIC **Mm**	MELANIC **Mm**	MELANIC **Mm**
P_2	MELANIC **Mm**	X	MELANIC **Mm**	
F_2	MELANIC **MM**	MELANIC **Mm**	MELANIC **Mm**	LIGHT **mm**

Figure 1.5 Genetics of inheritance of melanism in the peppered moth (Biston betularia), showing how the dominance of the gene for melanism **(M)** over the gene for lightness **(m)** results in the melanic form predominating very quickly indeed. This, coupled with the susceptibility of the light form to being eaten by predators, meant that the melanic form quickly became the only phenotype found in industrial areas.

survey from 1952 to 1970 (see Figure 1.6). It can be seen clearly that there are more light forms of the moth in the rural areas of Devon, north Wales and highland Scotland than the industrial belt between London and Birmingham and the industrial areas between northwest and northeast England. From this one example it is clear that animals (and plants) will adapt to pollution; this example, however, is a success story. How many species have disappeared because of the deleterious effects of pollution? Take the salmon for example; it was once common in many rivers, including the River Thames which flows through London. The presence of a salmon in the Thames is now headline news, and all because of the chemicals that we have poured into the river from the industry along its banks. There are of course many other examples of species disappearing from environments as urbanisation or industrialisation occurs; gone are the days that you could land a trout in the Hudson River as it flows out of New York in the USA.

The effects of carbon on our buildings and trees are obvious. Indeed an industry has built up around its removal—a trip to the beautiful city of Bath in the west of England might be rather disappointing because so many buildings are covered

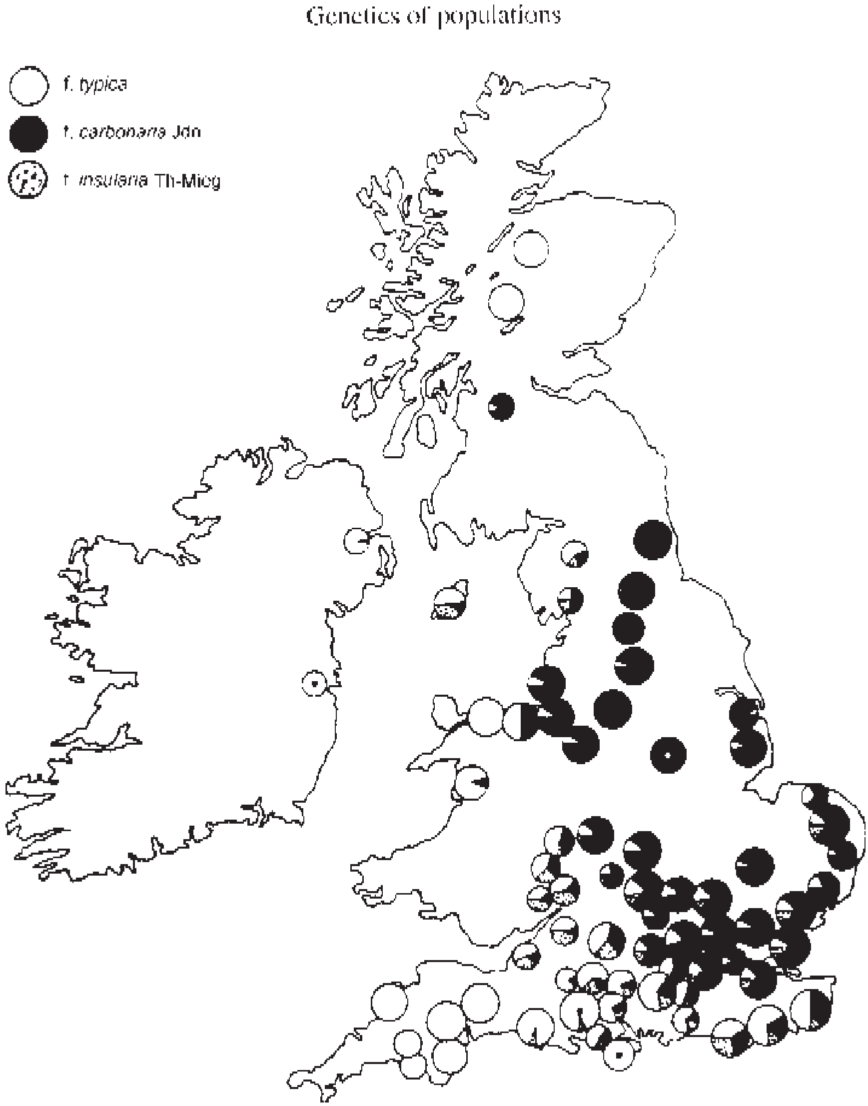

Figure 1.6 Distribution of the peppered and melanic forms of *Biston betularia* in Britain showing that the melanic form was commonest in and around industrial areas. From H.B.D. Kettlewell (1973), *The Evolution of Melanism with Special Reference to Industrial Melanism in the Lepidoptera,* Clarendon Press, Oxford.

with tarpaulin and plastic sheeting during the removal of this unsightly blackness. But what about the pollutants that we cannot see?

It is possible to trace back through many thousands of years the emission of invisible toxic gases. Combustion produces CO_2, NO_2 and SO_2. All are toxic by