



VINTAGE

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# A NEW GREEN HISTORY OF THE WORLD

CLIVE PONTING

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## ABOUT THE BOOK

Like Jared Diamond's *Guns, Germs and Steel*, Clive Ponting's book studies the relationship between the environment and human history. It examines world civilisations from Sumeria to ancient Egypt, from Easter Island to the Roman Empire and it argues that human beings have repeatedly built societies that have grown and prospered by exploiting the Earth's resources, only to expand to the point where those resources could no longer sustain the societies' populations and cause subsequent collapse.

This new edition of Clive Ponting's international bestseller has been revised, expanded and updated. It provides not only a compelling story of how we have damaged the environment for thousands of years but also an up-to-the-minute assessment of the crisis facing the world today - and the problems that have to be addressed in the search for solutions.

## ABOUT THE AUTHOR

Clive Ponting was until recently Reader in Politics and International Relations at the University of Wales, Swansea. His most recent books are: *World History: A New Perspective*; *Thirteen Days: The Road to the First World War*; *The Crimean War* and *Gunpowder: From the Alchemists of China to the Battlefields of Europe*. He recently took early retirement and now lives on a small Greek island where he is creating a Mediterranean garden and cultivating olives.

ALSO BY CLIVE PONTING

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*World History: A New Perspective*

*Thirteen Days: The Road to the Great War*

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CLIVE PONTING

A New Green  
History of the  
World

The Environment and the Collapse  
of Great Civilisations

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## PREFACE

The first edition of this book was published in 1991 and has since then been translated into thirteen languages. Over the last sixteen years much has changed in the world – the Soviet Union no longer exists and the Cold War has been replaced by the problems posed by the global dominance of the United States and the threat of terrorism. Much has also changed in the environment. Some of it has been for the better, for example the agreement to end the production of CFCs and eventually HCFCs in order to stop the destruction of the world's ozone layer. Many of the changes though have been for the worse. More than a billion extra people now live on the earth than when the first edition of this book was written. Billions of tonnes of carbon dioxide have been put into the atmosphere and the threat posed by global warming is even more starkly apparent. The destruction of the rainforests and other habitats has continued at an increasing pace.

I was therefore very pleased when Will Sulkin suggested that the time was ripe for a new edition of the book. I have taken this opportunity to completely revise the text. Every chapter, apart from the first, has been updated, revised, rewritten and expanded. One chapter has been dropped and a new one added. I have also greatly increased the number of charts and diagrams. In a world history it is inappropriate to use BC/AD and instead BCE (Before the

Common Era) and CE (Common Era) have been used instead. Where there is no ambiguity CE has been dropped.

At the end of the first edition I tried to strike a balance between pessimism and optimism when I wrote: 'Past human actions have left contemporary societies with an almost insuperably difficult set of problems to solve.' In the last sixteen years the balance was clearly tipped in favour of pessimism. It has been a period of wasted opportunities on environmental problems. Machiavelli wrote in *The Prince*:

In state affairs, by foreseeing [problems] at a distance, which is only done by men of talents, the evils which might arise from them are soon cured; but when, from want of foresight, they are suffered to increase to such a height that they are perceptible to everyone, there is no longer any remedy.

How well has the world's political leadership faced up to environmental problems over the last decade and a half? World industrial output and levels of consumption have continued to rise at unprecedented rates. The consequences, in resource and energy consumption and associated pollution, have become increasingly apparent. There can be no doubt that global warming is the greatest single threat that the world now faces. Over the last few years scientists have become increasingly concerned that the world's climate is about to reach a point where dramatic changes may happen very quickly and that these changes will be irreversible and bring in their wake major social and economic disruption. The action taken to meet this threat has been minimal. The United States refuses to do anything. The Kyoto treaty requires only very small reductions in carbon dioxide output; it only involves countries responsible for a third of the world's output and they are unlikely to meet the targets set in the treaty. By

the time that the effects of global warming become fully apparent, and that may be very soon, it will be too late to take action to avoid disaster. The world is now seeing the conjunction of a number of trends that emerged over the last two centuries, all of which are likely to lead to immense environmental problems in the next few years. This book tries to show just how deep-rooted these trends are in the way human societies have evolved.

I would like to thank Christopher Sinclair-Stevenson for commissioning the first edition of this book and Will Sulkin for his enthusiasm about a new edition. My greatest debt of gratitude though is to my wife, Laura, who drew all the maps, charts and diagrams for this new edition and who has given unstinting support throughout.

Clive Ponting  
Greece, 2007

# 1

## THE LESSONS OF EASTER ISLAND

Easter Island is one of the most remote inhabited places on earth. Only some 400 square kilometres in area, it lies in the Pacific Ocean, 3,200 kilometres off the west coast of South America and 2,000 kilometres from the nearest inhabitable land of Pitcairn Island. At its peak the population was only about 7,000. Yet, despite its superficial insignificance, the history of Easter Island is a grim warning to the world.

The Dutch Admiral Roggeveen, on board the *Arena*, was the first European to visit the island on Easter Sunday 1722. He found a society in a primitive state with about 3,000 people living in squalid reed huts or caves, engaged in almost perpetual warfare and resorting to cannibalism in a desperate attempt to supplement the meagre food supplies available on the island. During the next European visit in 1770 the Spanish nominally annexed the island but it was so remote, underpopulated and lacking in resources that no formal colonial occupation ever took place. There were a few more brief visits in the late eighteenth century, including one by Captain Cook in 1774. An American ship stayed long enough to carry off twenty-two inhabitants to work as slaves killing seals on Masafuera Island off the Chilean coast. The population continued to decline and conditions on the island worsened: in 1877 the Peruvians

removed and enslaved all but 110 old people and children. Eventually the island was taken over by Chile and turned into a giant ranch for 40,000 sheep run by a British company, with the few remaining inhabitants confined to one small village.

What amazed and intrigued the first European visitors was the evidence, amongst all the squalor and barbarism, of a once flourishing and advanced society. Scattered across the island were over 600 massive stone statues, on average over six metres high. When anthropologists began to consider the history and culture of Easter Island early in the twentieth century they agreed on one thing. The primitive people living in such poverty-stricken and backward conditions when the Europeans first visited the island could not have been responsible for such a socially advanced and technologically complex task as carving, transporting and erecting the statues. Easter Island therefore became a 'mystery' and a wide variety of theories were advanced to explain its history. Some of the more fantastic ideas involved visits by spacemen or lost civilisations on continents that had sunk into the Pacific leaving Easter Island as a remnant. The Norwegian archaeologist Thor Heyerdahl, in his popular book *Aku-Aku* written in the 1950s, emphasises the strange aspects of the island and the mysteries that lay hidden in its history. He argued that the island was first settled from South America and that from there the people inherited a tradition of monumental sculpture and stonework (similar to the great Inca achievements). To account for the decline he introduced the idea that at a late stage other settlers arrived from the west and began a series of wars between the so-called 'long-ears' and the 'short-ears' that destroyed the complex society on the island. Whilst this theory is less extravagant than some of the others that have been put

forward it has never been generally accepted by other archaeologists.

The history of Easter Island is not one of lost civilisations and esoteric knowledge. Rather it is a striking example of the dependence of human societies on their environment and of the consequences of irreversibly damaging that environment. It is the story of a people who, starting from an extremely limited resource base, constructed one of the most advanced societies in the world for the technology they had available. However, the demands placed on the environment of the island by this development were immense. When it could no longer withstand the pressure, the society that had been painfully built up over the previous thousand years fell with it.

The colonisation of Easter Island belongs to the last phase in the long-drawn-out movement of human settlement across the globe. The first people arrived sometime in the fifth century at a period when the Roman empire was collapsing in western Europe, China was still in chaos following the fall of the Han empire two hundred years earlier, India saw the end of the short-lived Gupta empire and the great city of Teotihuacan dominated most of Mesoamerica. They were Polynesians and part of a great process of exploration and settlement across the vast expanse of the Pacific Ocean. The original Polynesians came from south-east Asia and they reached the islands of Tonga and Samoa about 1000 BCE. From there they moved further east to the Marquesas Islands about 300 CE and then in two directions, southeast to Easter Island and north to Hawaii in the fifth century. The last phases of the movement were to the Society Islands about 600 and from there to New Zealand about 800. When this settlement was complete, the Polynesians were the most widely spread people on earth, encompassing a huge triangle from Hawaii in the north to New Zealand in the south-west and Easter



Island in the south-east - an area twice the size of the present continental United States. Their long voyages were made in double canoes, joined together by a broad central platform to transport and shelter people, plants, animals and food. These were deliberate colonisation missions and they represented considerable feats of navigation and seamanship since the prevailing currents and winds in the Pacific are against west-to-east travel.

When the first people found Easter Island, they discovered a world with few resources. The island was volcanic in origin, but its three volcanoes had been extinct for at least 400 years before the Polynesian settlers arrived. Both temperatures and humidity were high and, although the soil was adequate, drainage was very bad and there were no permanent streams on the island; the only fresh water available was from lakes inside the extinct volcanoes. Because of its remoteness the island had only a few species of plants and animals. There were thirty indigenous species of flora, no mammals, a few insects and two types of small lizard. The waters around the island contained very few fish. The arrival of the first humans did very little to improve the situation. The Polynesians in their home islands depended on a very limited range of plants and animals for subsistence: their only domesticated animals were chickens, pigs, dogs and the Polynesian rat and the main crops were yam, taro, breadfruit, banana, coconut and sweet potato. The settlers on Easter Island brought only chickens and rats with them and they soon found that the climate was too severe for semi-tropical plants such as breadfruit and coconut and extremely marginal for the usual mainstays of their diet, taro and yam. The inhabitants were, therefore, restricted to a diet based mainly on sweet potatoes and chickens. The only advantage of this monotonous, though nutritionally adequate, diet was that

the cultivation of the sweet potato was not very demanding and left plenty of time for other activities.

It is not known how many settlers arrived in the fifth century but they probably numbered no more than twenty or thirty at most. As the population slowly increased the forms of social organisation familiar in the rest of Polynesia were adopted. The basic social unit was the extended family, which jointly owned and cultivated the land. Closely related households formed lineages and clans, each of which had its own centre for religious and ceremonial activity. Each clan was headed by a chief who was able to organise and direct activities and act as a focal point for the redistribution of food and other essentials within the clan. It was this form of organisation and the competition (and probably conflict) between the clans that produced both the major achievements of Easter Island society and ultimately its collapse.

Settlements were scattered across the island in small clusters of peasant huts with crops grown in open fields. Social activities were centred around separate ceremonial centres, which were occupied for part of the year. The chief monuments were large stone platforms, similar to those found in other parts of Polynesia and known as *ahu*, which were used for burials, ancestor worship and to commemorate past clan chiefs. What made Easter Island different was that crop production took very little effort and there was therefore plenty of free time and labour which the clan chiefs were able to direct into ceremonial activities. The result was the creation of the most advanced of all the Polynesian societies and one of the most complex in the world for its limited resource base. The Easter Islanders engaged in elaborate rituals and monument construction. Some of the ceremonies involved recitation from the only known Polynesian form of writing called *rongorongo*, which was probably less a true script and

more a series of mnemonic devices. One set of elaborate rituals was based on the bird cult at Orongo, where there are the remains of forty-seven special houses together with numerous platforms and a series of high-relief rock carvings. The crucial centres of ceremonial activity were the *ahu*. Over 300 of these platforms were constructed on the island, mainly near the coast. The level of intellectual achievement of at least some parts of the Easter Island society can be judged by the fact that a number of these *ahu* have sophisticated astronomical alignments, usually towards one of the solstices or the equinox. At each site they erected between one and fifteen of the huge stone statues that survive today as a unique memorial to the vanished Easter Island society. It is these statues which took up immense amounts of peasant labour. The statues were carved, using only obsidian stone tools, at the quarry at Ranu Raraku. They were fashioned to represent in a highly stylised form a male head and torso. On top of the head was placed a 'topknot' of red stone weighing about ten tonnes from another quarry. The carving was a time-consuming rather than a complex task. The most challenging problem was to transport the statues, each some six metres in length and weighing several tens of tonnes, across the island and then erect them on top of the *ahu*.

The Easter Islanders' solution to the problem of transport provides the key to the subsequent fate of their whole society. Lacking any draught animals they had to rely on human power to drag the statues across the island using tree trunks as rollers. The population of the island grew steadily from the original small group in the fifth century to about 7,000 at its peak in 1550. Over time the number of clan groups would have increased and also the competition between them. By the sixteenth century hundreds of *ahu* had been constructed and with them over 600 of the huge

stone statues. Then, when the society was at its peak, it suddenly collapsed, leaving over half the statues only partially completed around Rano Raraku quarry. The cause of the collapse and the key to understanding the 'mysteries' of Easter Island was massive environmental degradation brought on by deforestation of the whole island.

When the first Europeans visited the island in the eighteenth century it was completely treeless apart from a handful of isolated specimens at the bottom of the deepest extinct volcano crater of Rano Kao. However, recent scientific work, involving the analysis of pollen types, has shown that at the time of the initial settlement Easter Island had a dense vegetation cover including extensive woods. As the population slowly increased, trees would have been cut down to provide clearings for agriculture, fuel for heating and cooking, construction material for household goods, pole and thatch houses and canoes for fishing. The most demanding requirement of all was the need to move the large number of enormously heavy statues to ceremonial sites around the island. The only way this could have been done was by large numbers of people guiding and sliding them along a form of flexible tracking made up of tree trunks spread on the ground between the quarry and the *ahu*. Prodigious quantities of timber would have been required and in increasing amounts as the competition between the clans to erect statues grew. As a result by 1600 the island was almost completely deforested and statue erection was brought to a halt, leaving many stranded at the quarry.

The deforestation of the island was not only the death knell for the elaborate social and ceremonial life, it also had other drastic effects on the everyday life of the population. From 1500 the shortage of trees was forcing many people to abandon building houses from timber and live in caves, and when the wood eventually ran out

altogether about a century later everyone had to use the only materials left. They resorted to stone shelters dug into the hillsides or flimsy reed huts cut from the vegetation that grew round the edges of the crater lakes. Canoes could no longer be built and only reed boats incapable of long voyages could be made. Fishing was also more difficult because nets had previously been made from the paper mulberry tree (which could also be made into cloth) and that was no longer available. Removal of the tree cover also badly affected the soil of the island, which would have already suffered from lack of suitable animal manure to replace the nutrients taken up by the crops. Increased exposure caused soil erosion and the leaching out of essential nutrients. As a result crop yields declined. The only source of food on the island unaffected by these problems was the chickens. As they became ever more important, they had to be protected from theft and the introduction of stone-built defensive chicken houses can be dated to this phase of the island's history. It became impossible to support 7,000 people on this diminishing resource base and numbers fell rapidly.

After 1600 Easter Island society went into decline and regressed to ever more primitive conditions. Without trees, and so without canoes, the islanders were trapped in their remote home, unable to escape the consequences of their self-inflicted environmental collapse. The social and cultural impact of deforestation was equally important. The inability to erect any more statues must have had a devastating effect on the belief systems and social organisation and called into question the foundations on which the complex society had been built. There were increasing conflicts over diminishing resources, resulting in a state of almost permanent warfare. Slavery became common and as the amount of protein available fell the population turned to cannibalism. One of the main aims of

warfare was to destroy the *ahu* of opposing clans. A few survived as burial places but most were abandoned. The magnificent stone statues, too massive to destroy, were pulled down. The first Europeans found only a few still standing when they arrived in the eighteenth century and all had been toppled by the 1830s. When they were asked by the visitors how the statues had been moved from the quarry, the primitive islanders could no longer remember what their ancestors had achieved and could only say that the huge figures had 'walked' across the island. The Europeans, seeing a treeless landscape, could think of no logical explanation either and were equally mystified.

Against great odds the islanders had painstakingly constructed, over many centuries, one of the most advanced societies of its type in the world. For a thousand years they sustained a way of life in accordance with an elaborate set of social and religious customs that enabled them not only to survive but to flourish. It was in many ways a triumph of human ingenuity and an apparent victory over a difficult environment. But in the end the increasing numbers and cultural ambitions of the islanders proved too great for the limited resources available to them. When the environment was ruined by the pressure, the society very quickly collapsed with it, leading to a state of near barbarism.

The Easter Islanders, aware that they were almost completely isolated from the rest of the world, must have surely realised that their very existence depended on the limited resources of a small island. After all it was small enough for them to walk round the entire island in a day or so and see for themselves what was happening to the forests. Yet they were unable to devise a system that allowed them to find the right balance with the environment. Instead, vital resources were steadily consumed until finally none was left. Indeed, at the very

time when the limitations of the island must have become starkly apparent the competition between the clans for the available timber seems to have intensified as more and more statues were carved and moved across the island in an attempt to secure prestige and status. The fact that so many were left unfinished or stranded near the quarry suggests that no account was taken of how few trees were left on the island.

The fate of Easter Island has wider implications. Like Easter Island the earth has only limited resources to support human society and all its demands. Like the islanders, the human population of the earth has no practical means of escape. How has the environment of the world shaped human history and how have people shaped and altered the world in which they live? Have other societies fallen into the same trap as the islanders? For the last two million years humans have succeeded in obtaining more food and extracting more resources on which to sustain increasing numbers of people and increasingly complex and technologically advanced societies. But have they been any more successful than the islanders in finding a way of life that does not fatally deplete the resources that are available to them and irreversibly damage their life support system?

## 2

### **THE FOUNDATIONS OF HISTORY**

Human history cannot be understood in a vacuum. All human societies have been, and still are, dependent on complex, interrelated physical, chemical and biological processes. These include the energy produced by the sun, the circulation of the elements crucial for life, the geophysical processes that have caused the continental land masses to migrate across the face of the globe and the factors regulating climatic change. These constitute the essential foundations for the way in which the various types of plants and animals (including humans) form complex, interdependent communities. Research in a wide variety of disciplines is increasingly making it clear that life on earth and all human societies depend on the maintenance of a number of delicate balances within and between a whole series of complex processes. These findings also help us understand the way in which the environment has influenced the development of human societies and, just as important, the human impact on the earth.

Human history has been affected by the action of large scale geological and astronomical forces over long periods of time. Although the amount of land on the globe has remained broadly constant, its distribution has altered radically. The rocks a few miles below the earth's surface are molten and flow in convection currents caused by the



heat rising from the earth's core. The flow causes movements in the earth's crust in the form of large 'plates' which move across the surface of the globe. The convection currents from the core of the earth well up in ridges under the oceans and then flow outwards, forcing the plates further apart so that the North Atlantic is currently widening at about a centimetre a year and the east Pacific by about ten centimetres a year. Material flows back down into the earth in the deep oceanic trenches. Where the plates meet there is major instability, causing earthquakes and volcanoes.

The effects of these movements can be seen in the natural disasters that have punctuated human history - volcanic eruptions such as Thera, which may have overwhelmed Minoan society on Crete, the eruption of Vesuvius that destroyed Herculaneum and Pompeii or major earthquakes such as that in the Senshi province in China in 1556 that killed over 800,000 people or those affecting Lisbon in 1755 and Tokyo in 1923 that killed tens of thousands. The impact in the long term is even greater. About 400 million years ago the earth had two supercontinents - Laurasia (North America, Europe and Asia) and Gondwanaland (South America, Africa, India, Australia and Antarctica) divided by the Tethys Sea. When this massive land mass broke up, the southern continents were situated over the south pole, causing glaciers in what is now Brazil and South Africa, and Laurasia was in the tropics. What is now North America broke away from Europe about 200 million years ago, although the major drift apart to form the Atlantic Ocean has only occurred in the last eighty million years. Gondwanaland began to break up into separate continents about 160 million years ago but the formation of most of the Indian Ocean and the break between Australia and Antarctica occurred in the last sixty

million years. Africa and South America split apart 100 million years ago.

The drift of the continents across the globe has had a profound impact on human history. It has determined the distribution of resources, and it accounts for the differing flora and fauna of the continents. Material welling up from the earth's core formed part of the continental land masses and determined the location and concentration of the world's mineral resources. The position of the continents at an earlier stage of their history explains the distribution of fossil fuel reserves in the modern world. Coal, oil and natural gas come from the decomposition of the vast tropical forests present about 250-300 million years ago. Continental drift has also been a major influence in determining the current distribution of plants and animals. Some have evolved in isolation and others have been driven to extinction by competitors when suddenly brought into contact with other parts of the world. For example, marsupial mammals had a worldwide distribution about eighty million years ago. As the continents drifted apart, marsupials were replaced in Eurasia by placental mammals. They survived in South America until it joined North America about thirty million years ago and they live on in Australia, which has remained isolated. The evolution of animals in different parts of the world has also had major effects on human history. The isolation of the Americas from the Eurasian landmass meant that animals domesticated in Europe and Asia such as sheep, goats, cattle and horses were not present. This influenced both their agriculture and their transport - domesticated animals were relatively unimportant and, although societies in the Americas were aware of the principle of the wheel, they could not utilise it because no draught animals were available.

Climate has been a fundamental force in shaping human history. Year-to-year variations in the weather influence crop yields but more significantly major, long-term trends have affected the ability of humans to settle parts of the globe, influenced the way plants and animals are distributed and placed limits on the crops that can be grown. The distribution of the continents has also been one of the factors determining climate. The ice ages, which have dominated the world's climate for the last two and a half million years, depend for their effect on the current distribution of the land masses of the northern hemisphere. Large scale ice sheets could not develop, and move further south when the climate became colder, without the continents clustering towards the north pole and the formation of a land-locked Arctic Ocean about three million years ago.

The position of the continents is only one factor influencing the world's climate. Apart from the steadily increasing energy output of the sun and the levels of gases such as carbon dioxide and methane in the atmosphere, the major factor determining climate is a series of astronomical cycles affecting the earth and its orbit round the sun. In the 1920s a Yugoslavian scientist, Milankovic, put forward his theory but was largely ignored. Only in the last thirty years, with scientific analysis of cores taken from ocean sediments and ice sheets giving information on climate stretching back over hundreds of thousands of years, have his theories been accepted. Over a period of 90-100,000 years the earth's orbit varies from being nearly circular to more elliptical. At present the orbit is becoming more circular and reducing the difference between the times when the heat from the sun falling on the earth is at its maximum and minimum. The second cycle, the timing of the earth's closest approach to the sun, is completed every 21,000 years. At the moment the earth is nearest to the sun during

the northern hemisphere winter. This reduces the impact of seasonal climatic change in the north whilst increasing it in the southern hemisphere. The third cycle affects the 'tilt' of the earth, which varies over a period of about 40,000 years. At the moment the tilt is decreasing, which again reduces the difference between the seasons. Although there are other short-term cycles, such as minor variations in the sun's output over a 22-23 year period (linked to sunspot activity and reversals of the solar magnetic field), it is the combination of the three long-term cycles that largely determines the earth's changing climate.

The long-term cycles alter the distribution of the sun's energy falling on to the earth. The current closeness of the continents in the northern hemisphere to the pole is of crucial importance because only a two per cent drop in heat from the sun during the northern summer can initiate glaciation. Cool summers allow winter snow and ice to survive to the next winter and the growing snow cover causes further cooling by increasing the reflectivity of the earth's surface. This further reduces the temperature in the northern hemisphere, leading to a rapid increase in the extent of the ice sheets and glaciers. The same process cannot work in the southern hemisphere when changes in the earth's orbit produce cool summers there. Apart from Antarctica there is insufficient land near to the pole and too much water (which moderates the temperatures) to allow continental ice sheets to form. For the last two and a half million years a cycle of ice ages has affected the earth's climate; the interglacial periods have normally been short, a total of 250,000 years out of the last two million. The warmest interglacial phase was about 120,000 years ago.

The various forms of life on earth, including humans, do not exist independently, they are part of ecosystems - a term which is used to refer to a community of organisms and their environment. There are many different types of

ecosystem such as a tropical forest, a grassland prairie or a coral reef but the foundation of all of them, and therefore the basis for life on earth, is photosynthesis - the process by which the energy of sunlight is used by plants and certain types of bacteria to create chemical compounds essential for life. Apart from the exotic life forms that live on the sulphur produced in deep ocean volcanic vents it is the only way that energy is introduced into the system. Very little of the sun's energy is, in fact, converted into matter and there is no way in which this efficiency can be improved since it depends on the amount of light falling on the earth, the laws of physics and the amount of carbon dioxide in the atmosphere. (Selective breeding of plants does not increase the efficiency of photosynthesis, it simply makes the plants put more of their effort into producing those parts that humans find useful at the cost of other parts.)

Within an individual ecosystem photosynthesisers (such as plants, trees and grasses) provide the basic energy input. They are the bottom of the food chain which links together all the different organisms. When photosynthesisers die they are broken down in the soil by decomposers such as fungi and their essential elements become available for other plants to use. (The pattern is similar in a marine environment.) Photosynthesisers are also eaten by animals (herbivores) which are able to extract essential nourishment from the plant. Herbivores are in turn eaten by other animals (carnivores) which are capable of extracting their food from animals. Some animals, known as top carnivores, can eat both herbivores and carnivores. When all these animals die their carcasses rot and the essential elements are recycled. Most ecosystems have complex food chains with numerous interrelationships between the various parts. However, behind this complexity there is an iron rule. The higher the animals is in the food

chain, the rarer it will be. Each step up the food chain is further removed from the primary production of the photosynthesisers, is less energy efficient and consequently the numbers that can be supported get smaller. This is why only a very small number of carnivores can exist within an ecosystem compared to the number of primary producers. In the case of a deciduous wood in southern England, almost 90 per cent of the primary production by the photosynthesisers (in this case trees, plants and grasses) eventually falls to the ground and decomposes on the woodland floor and another 8 per cent is stored as dead wood, which eventually decomposes. Less than 3 per cent is available for herbivores to eat and even less for the carnivores who have to live off the herbivores.

Ecosystems are not static. Over time they develop through an orderly and predictable series of changes resulting from the modification of the environment by the plants and animals themselves to culminate in a climax system which has the maximum possible number of plants and animals for the available energy input. It takes thousands of years to move from bare rock through lichens and mosses to ferns, plants and eventually trees to create a climax forest that can survive for very long periods - provided there is no human interference. The original pioneer species that colonise the rock are adapted to coping with poor soils or with none at all. Slowly, as decayed matter is accumulated, a better soil is created, capable of sustaining annual plants and successively perennials, grasses, shrubs and trees. As the ecosystem develops and changes, so do the plants and animals that can be supported. This development of an ecosystem has occurred countless times during the earth's history - for example the retreat of an ice sheet after a glacial period exposes bare rock, which within a few thousand years is converted into a climax temperate forest. Where a climax